EARTHQUAKE HAZARDS ASSOCIATED WITH THE VERDUGO-EAGLE ROCK AND BENEDICT CANYON FAULT ZONES, LOS ANGELES COUNTY, CALIFORNIA

F. Harold Weber, Jr., John H. Bennett,
Rodger H. Chapman, Gordon W. Chase, Richard B. Saul

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By F. Harold Weber, Jr., Geologist and principal investigator
John H. Bennett, Geodesist
Rodger H. Chapman, Geophysicist
Gordon W. Chase, Geophysicist
Richard B. Saul, Geologist

CALIFORNIA DIVISION OF MINES AND GEOLOGY (CDMG)
1416 Ninth Street, Sacramento, California 95814

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In Pocket

N O T E

This is the final of a series of technical reports to the U.S. Geological Survey describing results of studies by the California Division of Mines and Geology of the seismic hazards of faults of the central Los Angeles region: principally the Santa Monica, Hollywood, Raymond, Benedict Canyon, Verdugo and Eagle Rock fault zones. Initiator of the idea for these studies, preparer of proposals and principal investigator for the resulting projects from 1974 until leaving state service at the end of August 1979 is Robert L. Hill. The principal technical reports in addition to the present one are listed under "References Cited" (Hill and others, 1976, 1977, 1979a,b).

EARTHQUAKE HAZARDS ASSOCIATED WITH THE VERDUGO-EAGLE ROCK AND BENEDICT CANYON FAULT ZONES, LOS ANGELES COUNTY, CALIFORNIA

CHAPTER A

SUMMARY AND RECOMMENDATIONS

By F.H. Weber, Jr., J.H. Bennett, R.H. Chapman,
G.W. Chase and R.B. Saul

The Verdugo, Eagle Rock and San Rafael fault zones compose a system of faults about 32 km in length that extends southeasterly from the south edge of the Pacoima Hills at the north edge of the San Fernando Valley to Pasadena where the San Rafael fault apparently terminates against the Raymond fault zone. Faults of the system generally separate pre-Late Cretaceous igneous and metamorphic rocks of the Verdugo Mountains and San Rafael Hills on the northeast from Cenozoic sedimentary rocks and sediments of the San Fernando Valley and other lowlands on the southwest. At the northwest end of the system, the Verdugo fault probably bends westward and joins the Mission Hills fault zone, although it may be truncated by an east-trending fault (not recognized at the ground surface) which lies between the Mission Hills and Northridge Hills faults.

Faults of the Verdugo - Eagle Rock - San Rafael system dip gently to steeply northward, but only along the west part of the Eagle Rock fault are dips well-defined (15-30° north). The most active segment of the system may be the Verdugo fault between Verdugo Wash on the southeast and Big Tujunga Wash on the northwest, a distance of 20 km. Along this segment of the Verdugo fault, well-defined south-facing breaks in slope in the uppermost part of alluvial fans of late Quaternary (including Holocene) age in the Burbank - west Glendale area bordering the Verdugo Mountains apparently are relatively youthful fault scarps. These scarps are 2 or slightly more meters in height but the details of their morphology have been obliterated by development in this area. These scarps not only lie at the base of the steepest and highest part of the Verdugo Mountains but they also coincide with a steep gravity gradient. Northwest of these scarps, in the Sun Valley area, a sand and gravel pit along the zone once exposed minor faults cutting very late Quaternary sand and gravel deposits of Big Tujunga Wash at a depth of nearly 45 m beneath the ground surface. These faults are now covered by fill.

The Benedict Canyon fault zone trends diagonally eastward through the Santa Monica Mountains and along the north edge of the easternmost part of the mountains, at the south edge of the easternmost part of the San Fernando Valley, and extends eastward toward the Eagle Rock fault zone. The fault is part of the Hollywood - Santa Monica - Raymond system. No surface evidence was found during this study for evaluating the recency of activity of the Benedict Canyon fault zone. The only evidence for relatively recent movement along it occurs in the subsurface slightly east of the Santa Monica Mountains where the very gently north-sloping base of apparently youthful ground water-bearing sediments is offset downward relatively to the north about 125 m, based on differences in total depth of alluvial deposits in two nearby water wells. The fault in this vicinity coincides with a steep north-dipping gravity gradient. No remnants of scarps or other surface features of faulting are preserved in this part of the Los Angeles River drainage which has been in a state of rapid aggradation during Holocene time.

This system of east-trending faults made up by the Hollywood, Santa Monica and Raymond faults in the study area contains many surface features which indicate that it has been active during latest Quaternary (probably Holocene) time. Especially noteworthy are east-trending, south-facing breaks in slope as high as 2-3 m that occur along the Hollywood fault in the Atwater - Glassell Park area, which is underlain by Holocene floodplain deposits adjacent to the Los Angeles River Channel. These apparent scarps occur approximately above alluvial beds that are depicted in a cross section by Williams and Wilder (1971) to be off set downward relatively on the south side of a subsurface fault about 35 m.

Based on offset alluvial sediments and other geologic evidence, both the Verdugo and Hollywood fault zones are judged to have been active during very late Quaternary (including Holocene) time. The fact that scarps 2-3 meters high are preserved in youthful alluvial sediments in a relatively humid climate with rapid alluviation caused by voluminous sediment runoff from the nearby mountains during heavy rains at least one winter in every 10 or 15 years is considered to be ample proof that the faults have been active in latest Quaternary time. Also apparent is that geomorphic features indicating very late Quaternary movement are more abundant, more pronounced and better preserved along the eastern Hollywood and western Raymond fault zones than they are along the Verdugo, Eagle Rock and San Rafael fault zones. Accordingly, it appears that, overall, the features along the former faults are the result of larger and/or more frequent earthquakes than those of the latter faults.

In addition, relatively recent tectonic activity in the study area is suggested by localized changes in elevation disclosed by the precision survey net of the City of Los Angeles. For example, repeated surveys by the City of Los Angeles disclose that a subsidence trough extends eastward through the North Hollywood area of the San Fernando Valley. This trough occurs over a gravity low and may be the result of tectonic downdropping between two concealed faults or along a syncline, perhaps accentuated by the withdrawal of ground water. Also, additional tectonic features, possibly active in latest Quaternary time, are inferred from geologic, gravity, ground water and elevation change data to lie beneath the alluvial surface of the eastern San Fernando Valley.

More precise zones of possible fault rupture during future earthquakes than is shown by the present mapping could be delineated by very detailed field mapping along faults of the study area. Such mapping would consist of a very careful amalgamation at large scale of geologic, elevation change, ground water and geophysical data, augmented by trenching. Targets especially important for such future projects are the Verdugo fault zone in the Glendale - Burbank area and the eastern Hollywood - western Raymond fault zones in the

Hollywood - Glassell Park - Highland Park areas. Features of surface faulting in these areas are well-developed; and the areas are especially populous and contain many high-rise buildings, schools, hospitals and older, especially earthquake-prone buildings. New buildings will continue to be constructed as older areas are redeveloped. Additional targets of such analysis of surface features of faulting could be the Northridge Hills and other known and possible faults of the San Fernando Valley.

CHAPTER B

GEOLOGICAL FEATURES RELATED TO CHARACTER AND RECENCY OF MOVEMENT ALONG FAULTS, NORTH-CENTRAL LOS ANGELES AREA, LOS ANGELES COUNTY, CALIFORNIA

by F. Harold Weber, Jr.

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ILLUSTRATIONS

I. INTRODUCTION

This report summarizes the results of a study of the character and recency of movement and accompanying geology of faults of the north - central Los Angeles area (figures 1 and 2). The study has been directed primarily at the Verdugo-Eagle Rock-San Rafael fault zone, but also includes the eastern parts of the Northridge Hills and Benedict Canyon faults, the eastern part of the Hollywood fault zone and the western part of the Raymond fault zone. The present report and geologic map (plate 1) succeed a preliminary report and map published _in_ Hill and others, 1979b (Weber, 1979b).

Geologic mapping in the study region by the writer was done between February 1979 and July 1980. The work began with a framework of general and specific knowledge provided by R.L. Hill. Also helpful were the basic references to the geology of the region, including reports by Association of Engineering Geologists (1975), California Water Rights Board (1960, 1962; summarized by Brown, 1975), Durrell (1954), Eckis (1934), Hill and others (1976, 1977, 1979a,b), Lamar (1970), Oakeshott (1958; 1975, editor), Proctor (1974, 1975), R.T. Frankian and Associates (1968), Schnurr and Koch (1979), Woodford and others (1954), Yerkes and others (1965) and Ziony and others (1974). An unpublished report on the geology of the western San Gabriel Valley area by H.E. Stark and J.E. Thompson (1970), lent to R.L. Hill and the writer in August 1979 by Stark through the

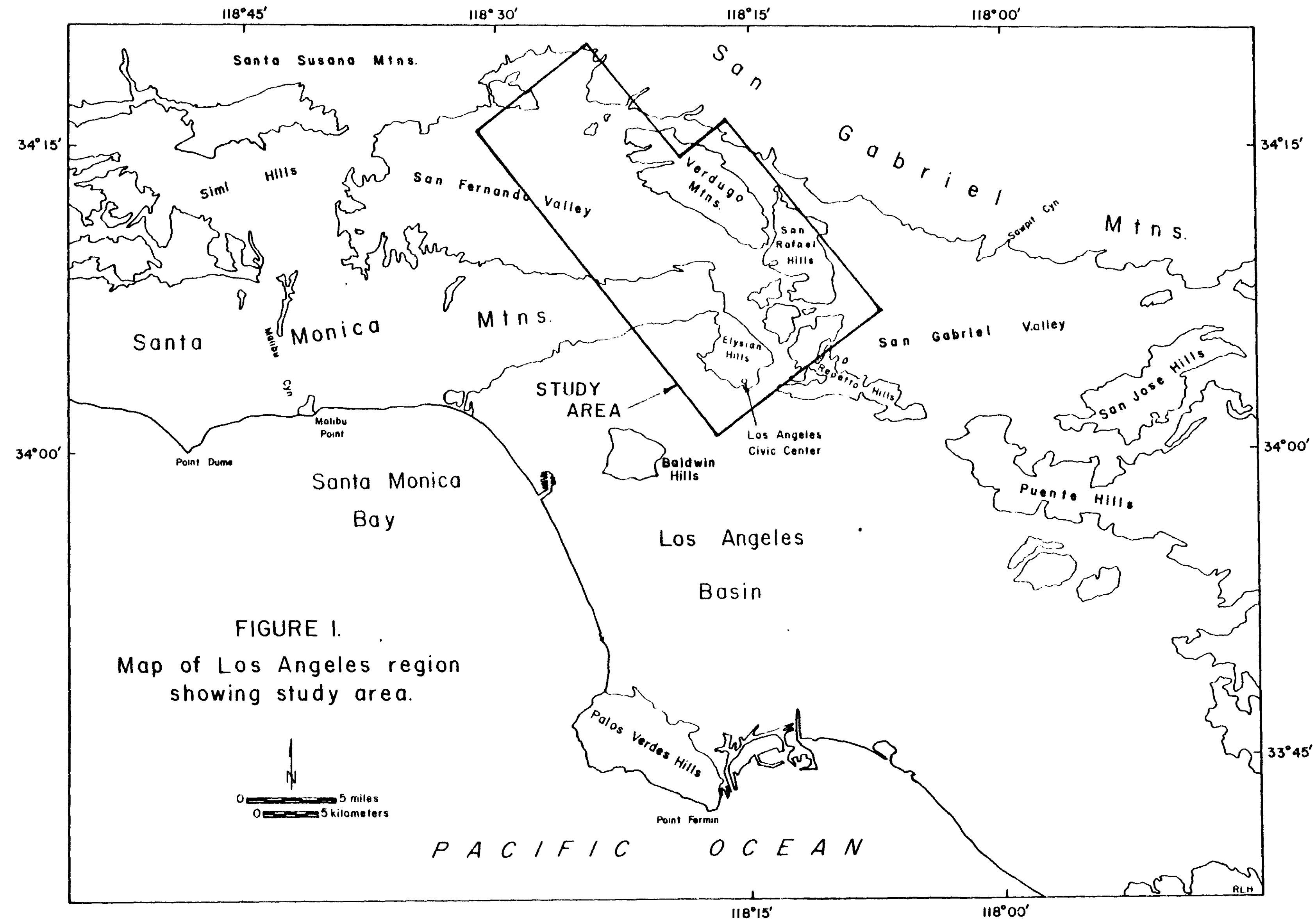


FIGURE I.
Map of Los Angeles region showing study area.

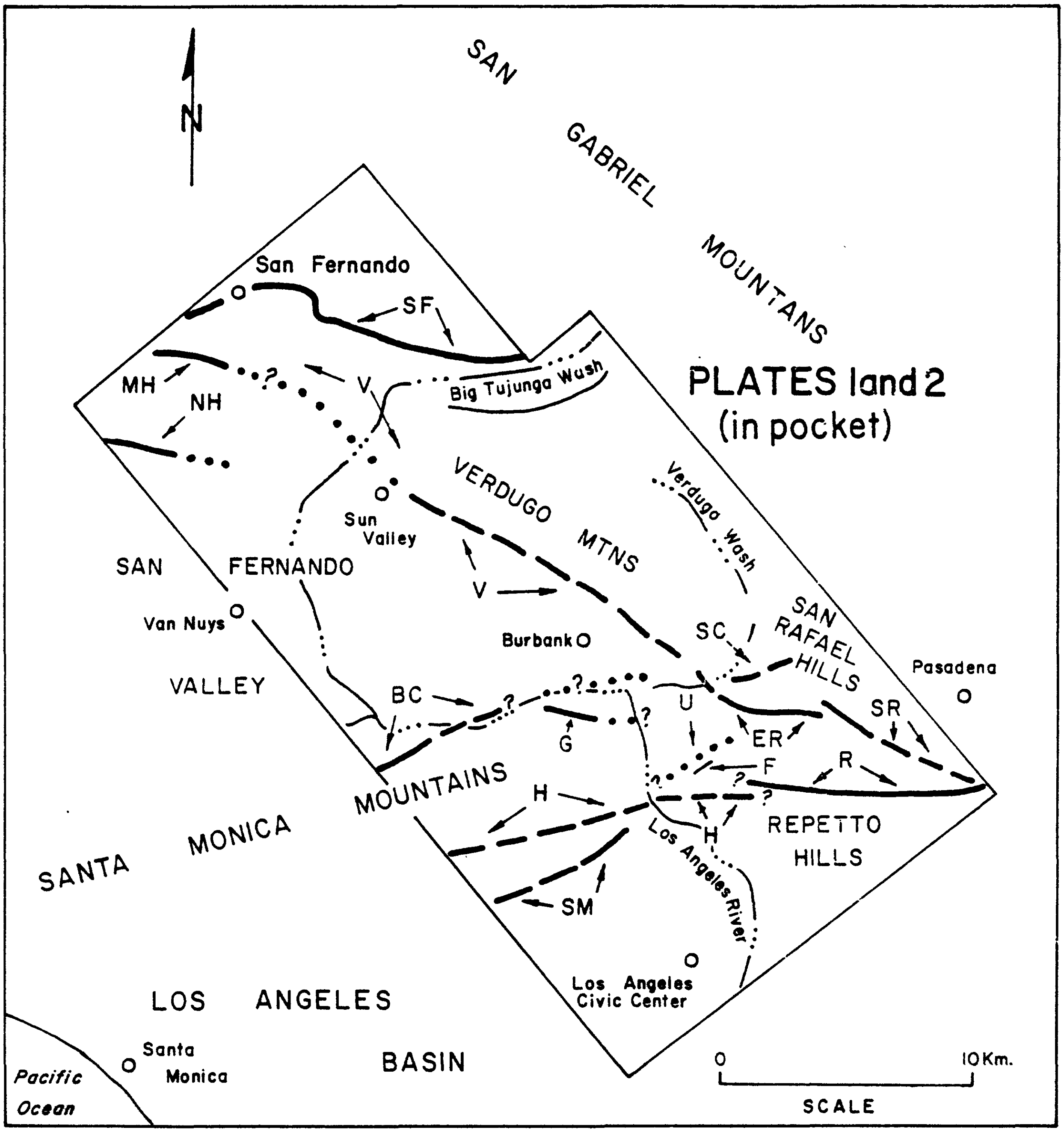


Figure 2. Index map showing study area and following faults that are discussed herein: BC - Benedict Canyon; ER - Eagle Rock; F - Forest Lawn; G - Griffith; H - Hollywood; MH - Mission Hills; NH - Northridge Hills; R - Raymond; SC - Sycamore Canyon; SF - San Fernando; SR - San Rafael; SM - Santa Monica; U - Unnamed; V - Verdugo. Additional features described in text consist of possible concealed faults of the eastern San Fernando Valley that are shown on plates 1 and 2d.

courtesy of Cities Service Oil Company, was very useful in evaluating the geology of the northern Repetto Hills along the south side of the Raymond fault zone. Full titles for these and other references are listed under "References Cited."

The work of Rodger Chapman and Gordon Chase (plate 2a, Bouguer gravity map), Richard Saul (plate 2b, map of water table; and aerial photograph interpretation) and Jack Bennett (unpublished profiles showing elevation changes) constituted basic sources for findings developed in this chapter. Carl Houser, of Conrock, showed rock exposures and other geologic features of the company's sand and gravel pits in Sun Valley to the writer and R.B. Saul. C. Michael Scullin, formerly geologist for the City of Glendale, discussed the geology of the Glendale area with the writer, and Howard E. Stark provided an enlightening discourse on his and J.E. Thompson's aforementioned report to the writer and R.L. Hill.

Clerical staff work for the report was provided by Wilma Ashby, Venice Huffman, Esther NeSmith, and Sue Torres. Cartographic services were provided by Elizabeth Lindgren and Victor Protasov, and the writer was assisted in the drafting of Plate 1 by his daughter, Robin I. Weber. R.L. Hill has given the writer much technical consultation both before and after leaving state service. Edward C. Sprotte furnished data on exploratory oil wells. Allan G. Barrows of the Division of Mines and Geology staff very carefully and helpfully reviewed the 1979 and 1980 editions of the report. David J. Beeby made a final review.

II. REGIONAL GEOLOGY

A. Geomorphic setting of faults

The study area consists of groups of bedrock hills and mountains that are separated by alluvium-filled valleys underlain by bedrock apparently similar to that of the hills and mountains (figure 1). The two principal highlands are the Verdugo Mountains-San Rafael Hills and the Santa Monica Mountains, which are separated by the San Fernando Valley. The complex pattern of faulting in the area has at least partly influenced the development of the highland-lowland terrain (figures 2 and 3). For example, the east-southeast trending highland comprised of the Verdugo Mountains and San Rafael Hills has risen along the northeast side of the Verdugo - Eagle Rock - San Rafael fault system, and the San Fernando Valley has been downdropped to the south of the mountains principally along the Verdugo zone of this system on the north and along a complex system of faults on the south. These faults are only partly exposed at the ground surface. Where they are concealed, their presence and location are made evident or are inferred by use of geophysical, ground water and elevation change data. One such poorly exposed fault is the Benedict Canyon fault east of Cahuenga Pass, along the south edge of the eastern San Fernando Valley.

The eastern part of the Santa Monica Mountains is bounded on the south by the Hollywood fault zone, which, along with the Santa Monica fault zone and several other structures in the area mapped, is a part of the major structural boundary that separates the Transverse Ranges province on the north

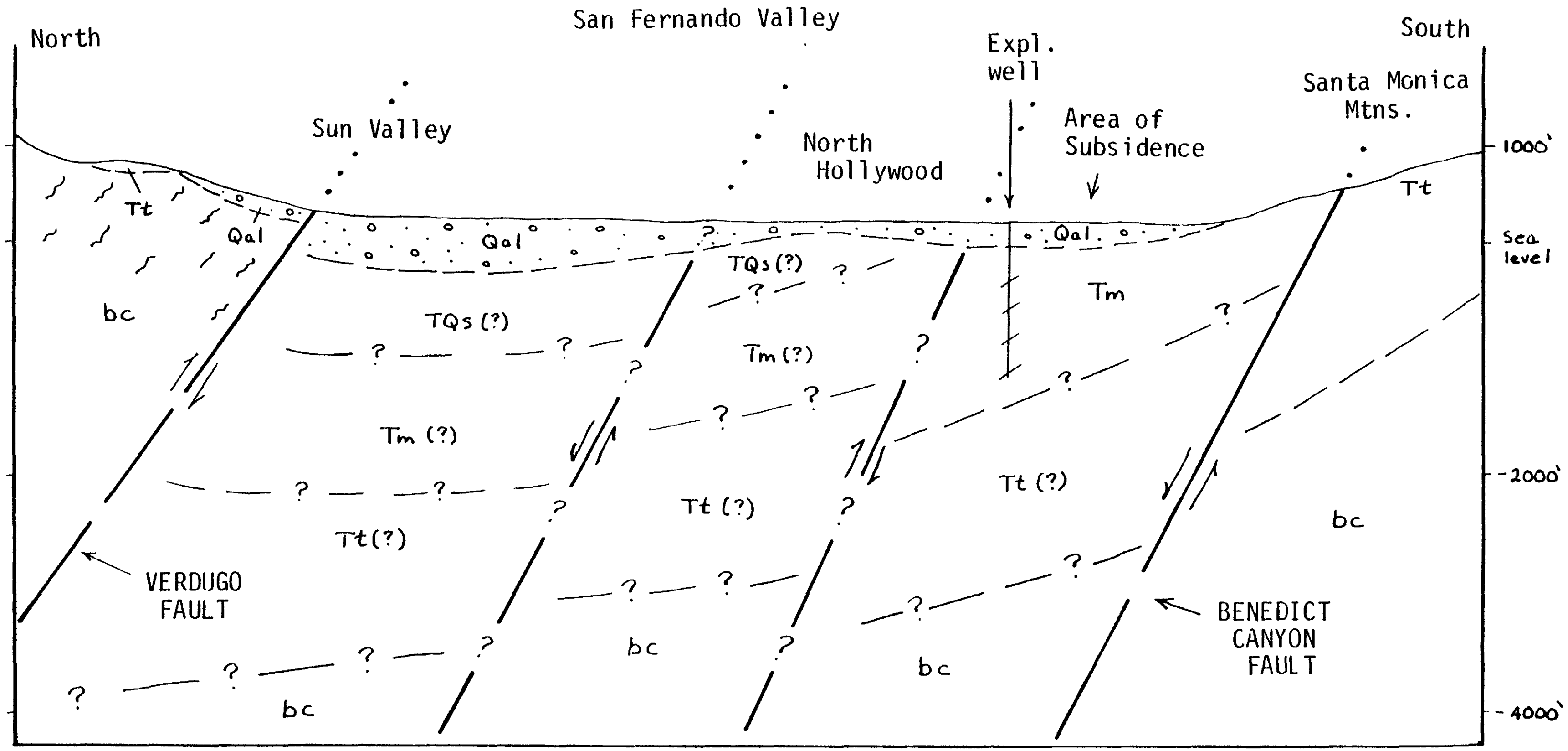


Figure 3. Pictorial cross section through the eastern San Fernando Valley showing inferred fault relationships based on a variety of sources. The two middle faults simplify a relationship that may involve much more complicated structure (plates 1 and 2c). [Vertical scale is exaggerated about 4 times and horizontally the diagram is not drawn to scale; symbols - Qal, older and younger alluvium; TQs, Saugus Fm.; Tm, Modelo Fm.; Tt, Topanga Fm. and volcanic rocks; bc, basement complex; expl. well = Continental Hollywood Freeway No.2., showing dips recorded by downhole dipmeter in the Modelo Fm.]

from the Peninsular Ranges province on the south. The eastern part of this structural boundary within the area studied consists of the Raymond fault zone, which is bordered on the south by the Repetto Hills.

B. Geologic setting and offsets of rock units along faults

The oldest rocks in the region consist of Cretaceous and older holocrystalline igneous and metamorphic rocks that make up the so-called basement complex. These rocks are overlain by sedimentary rocks of Late Cretaceous, Tertiary and early-mid Quaternary age, by volcanic rocks of mid-Miocene age and by older and younger alluvial sediments of late Quaternary age.

1. Basement rocks. The Verdugo Mountains and San Rafael Hills consist almost wholly of igneous and metamorphic rocks that appear to be equivalent to rocks nearby to the north in the San Gabriel Mountains south of the San Gabriel fault zone (mapped as Tujunga complex by Weber, 1979a). The basement rocks in the study area consist principally of medium to dark gray gneissic quartz diorite and diorite and quartz dioritic and dioritic gneiss of undetermined age that are intruded by irregularly shaped bodies of pale to medium gray equigranular granitic rocks (grt) and accompanying pegmatite and aplite dikes. The granitic rocks consist mostly of quartz diorite and granodiorite. Accompanying the gneissic and granitic rocks are bodies of marble (mostly as thin discontinuous layers; mapped as "ma"), bodies of quartzite (not mapped) and uncommon garnet schist and hornfels (not mapped). Two very thin layers of graphite schist (gs) were mapped.

An unmapped body of graphite schist that was once prospected occurs in the eastern slope of the Verdugo Mountains (Beverly, 1934). An irregularily shaped body of foliated gabbro was mapped in the westernmost La Tuna Canyon area. The gabbro was also mapped by Johnston (1938).

In general, the foliation of the gneissic and other rocks of the Verdugo Mountains and San Rafael Hills strikes northwesterly and dips moderately to steeply northeasterly. The trend of foliation is generally similar to that of rocks in the San Gabriel Mountains to the north. Most of the marble layers occur in the northwest part of the Verdugo Mountains, where the igneous and metamorphic complex was mapped as mm + grt (Tujunga complex: metamorphic rocks, including marble, intruded by granodiorite and quartz diorite). To the southeast, where marble layers are very sparse to absent, the basement rocks were mapped as m + grt (Tujunga complex: metamorphic rocks, marble very sparse to absent, intruded by granodiorite and quartz diorite). Only a few bodies of the intrusive granodiorite and quartz diorite were mapped for this study, because the boundaries of these bodies are very difficult to ascertain without very tedious, detailed mapping.

In the Verdugo Canyon area, small areas of the foliated rocks resemble finer-grained parts of the Lowe Granodiorite of the San Gabriel Mountains. In particular, some of these rocks in the Verdugo Canyon areas (localities on plate 1 designated by locality 40, Appendix 1), resemble parts of the "hornblende facies" (border rocks) of Ehlig (1975, figure 1) as exposed on Mount Gleason Road and they also resemble exposures of apparent Lowe Granodiorite observed by the writer along Upper Clamshell truck trail at the head of Sawpit Canyon, in the San Gabriel Mountains. The marble-bearing metasedimentary rocks of the western San Gabriel

Mountains were named Placerita Formation by Miller (1934) who surmised, as did Oakeshott (1958), that they are possibly Paleozoic in age. It is not clear whether the marble, quartzite and graphite schist are interlayered with the gneissic rocks or whether the gneissic rocks were metamorphosed after being intruded into the marble and other metasedimentary rocks.

Basement rocks of the Santa Monica Mountains (grsm) crop out discontinuously, partly brought up to the surface by fault movements and partly as erosional windows surrounded by overlying younger sedimentary and layered volcanic rocks. In the easternmost part of the mountains and in their probable structural continuation east of the Los Angeles River, the basement consists principally of pale gray granitic rocks (mostly granodiorite and quartz diorite ?), with a much smaller proportion of metamorphic inclusions than occur in the terrane of the Verdugo Mountains and San Rafael Hills. The basement rocks of the eastern Santa Monica Mountains were studied by Neuerburg (1951a) who divided them into units which he named and mapped.

No specific evidence bearing on the amount of displacement of the basement rocks has been uncovered during this study. Because the rocks of the Verdugo Mountains are so similar to the rocks of the western San Gabriel Mountains and seem nearly structurally continuous with them across Tujunga Valley, there seems to have been very minimal lateral offset of them along faults of the Sierra Madre and San Fernando fault zones which separate the San Gabriel and Verdugo Mountains (figure 4). These latter rocks resemble basement rocks of the Sawtooth Mountains, in the vicinity of Elizabeth Lake Canyon, about 40-50 km to the north of the Verdugo Mountains, which also contain bodies of marble and graphite schist and were inferred to be correlative by Ehlig (1975, figure 1).

Because the basement terrane of the Verdugo Mountains and San Rafael Hills contrasts with that of the Santa Monica Mountains, there may be a major, if ancient, fault separating the two terranes. Such a fault has been postulated by D.M. Morton and F.K. Miller, of the U.S. Geological Survey, based on their regional studies of the absolute ages of the basement rocks of the Transverse Ranges (D.M. Morton, U.S. Geological Survey, personal communication, 1979 and 1980). This fault could be the Verdugo - Eagle Rock fault zone or it could lie to the south of the Verdugo fault within the San Fernando Valley. Cross section B-B' by N. Smith (in Schnurr and Koch, 1979) shows such a fault to lie at the south edge of the central San Fernando Valley. Yerkes and others (1965, figure 2) inferred a concealed, northwest-trending fault in the east part of the San Fernando Valley to separate the portion of the basement floor to the south, which they estimate to lie at depths as great as 3,000 m, from the basement floor to the north, which they indicate lies at depths of only about 1800 m and less.

The Hollywood and Raymond fault zones are part of a major structural boundary separating the Transverse Ranges on the north from the Peninsular Ranges on the south. As much as 90 km of left slip of lower Miocene and older rocks along this system has been postulated by Yeats (1968), Yerkes and Campbell (1971, Campbell and Yerkes (1976) and others, Yerkes and others (1965, p. A51), reiterating the work of McCulloh (1957), note the presence of slate in a well (P21, Appendix 2, herein) in Elysian Park, south of the Hollywood - Santa Monica fault zone. This locality is about 9 miles (15 km) east of the largest exposure of slate of the Santa Monica Formation which lies to the north of the fault zone in the Santa Monica Mountains. These writers state

Figure 4. Generalized geologic map of the Los Angeles region. [Explanation: Hachured contact separates terrane to west (KT) in which sedimentary rocks of Late Cretaceous and early Tertiary age lie on basement floor,and are commonly overlain by middle Miocene and younger rocks, from terrane to east (T) in which the rocks of Late Cretaceous and early Tertiary age are absent beneath middle and late Miocene rocks. Additional explanation: sediments and rocks - Qal, alluvium; Gr - granitic rocks of Santa Monica Mountains area; SM - Santa Monica Fm. (slate); BC - basement complex of the San Gabriel Mountains south of the San Gabriel fault; faults - BCa, Benedict Canyon; H, Hollywood; HP, Highland Park, MC, Malibu Coast; MH, Mission Hills; NH, Northridge Hills; R, Raymond; S, Simi; SF, San Fernando; SG, San Gabriel; SMa, Sierra Madre; SMo, Santa Monica; SS, Santa Susana; VE, Verdugo-Eagle Rock - San Rafael; folds - SFS, San Fernando Valley syncline; wells - data for exploratory oil wells are from Appendix II, wells P12, 13, 20, 22 and 23; the two most westerly wells, without depths given, are from Yeats (1973, fig. 2]

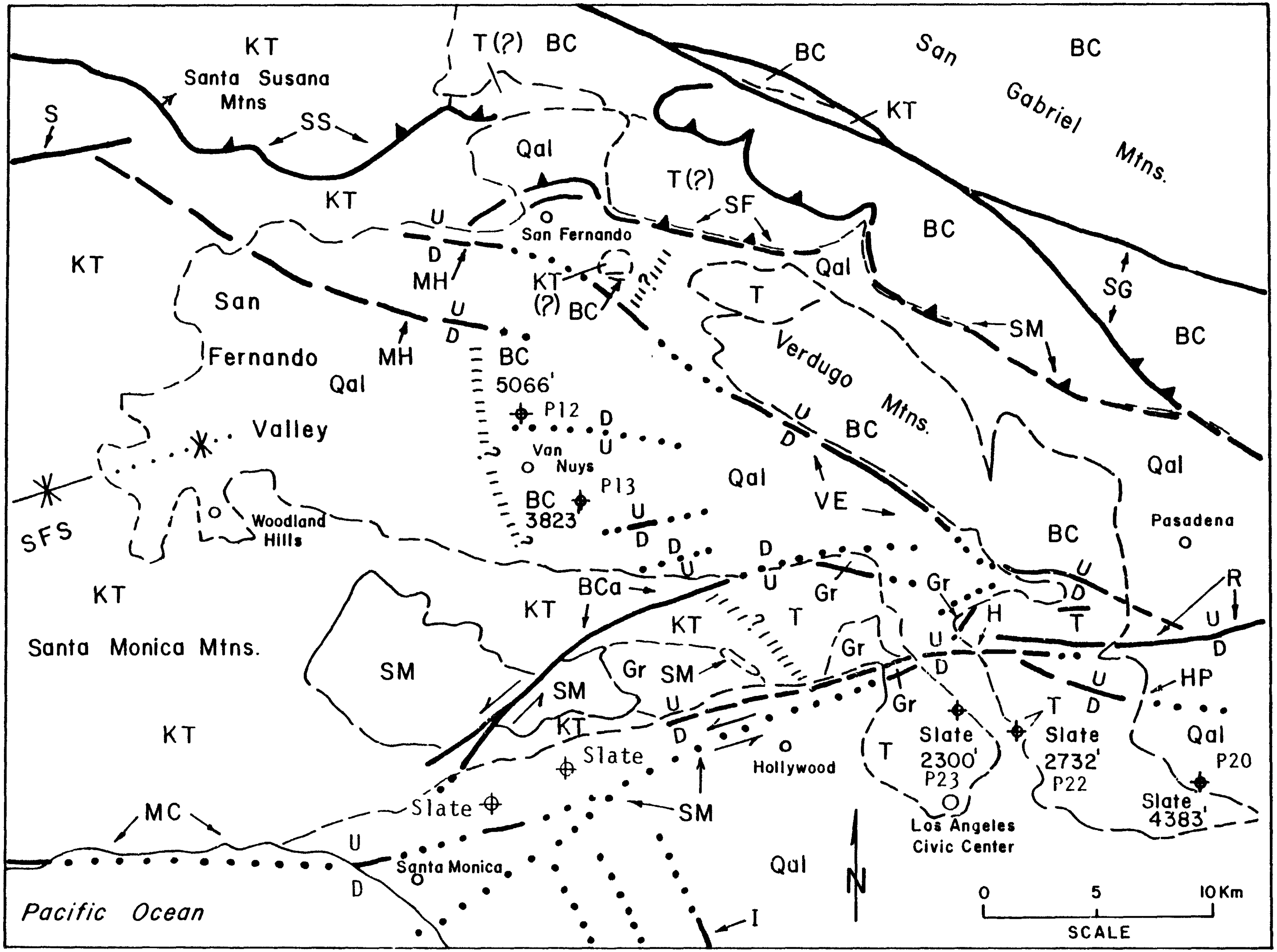


Figure 4. For caption see opposite page.

that this relationship suggest left lateral offset along the Hollywood - Raymond fault system. The relative positions of slate exposed in the Santa Monica Mountains (Figure 4, symbol SM) and in two wells (after Yeats, 1973, figure 1) to the south of the mountains but north of the Santa Monica - Hollywood - Raymond fault system, and in 3 wells south of the fault system (P21, 22, 23), suggest that left slip of the slate rocks along the fault system could be at least 25 km but not suggestive of the 90 km postulated by Yeats (1968) and others. With regard to vertical offset of the basement floor, Yerkes and others (1965, p. A51) state that it is upthrown relatively upward along the north side of the fault system more than 7,500 feet (2,290 m) in the Beverly Hills area.

2. Upper Cretaceous to Lower Miocene rocks. Predominantly clastic, marine sedimentary rocks (KTe) of Late Cretaceous and Paleocene age crop out in the western part of the study area in the eastern Santa Monica Mountains where they rest depositionally partly on granitic rocks and partly on Santa Monica Formation ("slate"), of Jurassic age. They generally dip north and are overlain by volcanic and sedimentary rocks of middle Miocene age which also generally dip north (Durrell, 1954; Harding, 1952; Hardey, 1958; and Elliot, 1951). These rocks exhibit slightly more than 2.5 km of left separation along the Benedict Canyon fault, as portrayed by Durrell (1954), including relationships west of the present study area.

A small exposure in the Pacoima Hills of nonmarine conglomerate faulted against gneissic rocks and overlain by volcanic rocks was mapped by Oakeshott (1958) as Topanga Formation but the rocks there appear to the writer to resemble Sespe Formation exposed to the west in the Simi Valley area (where the unit is also overlain by volcanics).

Upper Cretaceous to lower Miocene rocks have been reached by exploratory oil wells in the subsurface of the western San Fernando Valley. In the central and eastern parts of the Valley, however, most wells have bottomed in either granitic or gneissic basement rocks or sedimentary rocks apparently of middle to late Miocene age. Because Upper Cretaceous and Paleocene sedimentary rocks seemingly underlie middle and upper Miocene rocks only in the west San Fernando Valley and not in the east part, it seems possible that the eastern limit of the Upper Cretaceous - Paleocene terrane of the west valley could be offset left laterally 7 to 10 km along concealed faults of the San Fernando Valley from its counterpart in the Cahuenga Pass area of the eastern Santa Monica Mountains (figure 4 and plate 1).

3. Middle Miocene rocks. Layered volcanic and sedimentary rocks of middle Miocene age are exposed widely in the study area, including the Santa Monica Mountains and the hilly area to the east, the southern edge of the San Rafael Hills (south of the Eagle Rock and San Rafael faults), the easternmost Verdugo Mountains and the Pacoima Hills. Also, they have been reached by exploratory oil wells in the north central San Fernando Valley (Wells P 6 and 10, Appendix 2). The volcanic rocks consist mainly of basaltic flows and flow breccias which are exposed in the Santa Monica Mountains but not to the east.

The sedimentary rocks of this age in the eastern Santa Monica Mountains were assigned to the Topanga Formation by Hoots (1931). This formation was named by Kew (1923) from exposures in the Topanga area in the western Santa Monica Mountains. In the present study area, geologists have also used Kew's and Hoot's terminology. The easternmost Topanga Formation in the study area occurs in the vicinity of Highland Park and Pasadena and consists of coarse to very coarse conglomerate-breccia (Ttcb) composed mostly of angular to subangular clasts ranging up to 1 m in length of granitic and gneissic rocks. The sediments were presumably derived from ancient mountainous terrain nearby to the north and rapidly deposited southward and westward in steep debris fans into a marine basin which had recently opened in middle Miocene time.

The conglomerate-breccia gradually thins westward in the Santa Monica Mountains, where it becomes interlayered with more abundant beds of sandstone and siltstone (Tts), beds of conglomerate (Ttc) containing abundant rounded clasts of quartzite and metavolcanics and layers of volcanic rocks (Tv). The conglomerate-breccia is essentially absent at the west edge of the study area and the only coarse clastic beds there are those of conglomerate (Ttc). Volcanic rocks of the Santa Monica Mountains are mainly basaltic in composition and consist of pillow breccia, flows, and volcanic conglomerate (Neuerburg, 1953; and others). Coarse conglomerate and minor interlayered volcanics also occur at the west end of the Verdugo Mountains where the lowermost part of the conglomerate was mapped as Topanga Formation by Beatie (1958) and is shown entirely as Topanga Formation (Ttc) herein on Plate 1.

Fossils are sparse in rocks of the Topanga Formation. East of the Santa Monica Mountains, in the Adams Hill area of Glassell Park, foraminifera and fish scales representative of the upper part of the Luisian stage occur near the base of the Formation (Lamar, 1970, plate 1 and p. 19). From a nearby locality slightly higher stratigraphically, Weldon (1955, plate 1, p. 22-23) made a collection of poorly preserved fish scales that were identified by Richard Pierce as representing either latest middle or late Miocene time. Fish scales from a locality south of Cahuenga Peak in the Santa Monica Mountains were compared by W.T. Rothwell with similar fish scales that occur at two localities in rocks more clearly identified to be Topanga Formation elsewhere in southern California (Neuerburg, 1953). Foraminifera collected by A.L. Parmer of Caltrans from a cut made for widening of the Hollywood Freeway, about 0.6 km southeast of the Hollywood Bowl, and mostly stratigraphically beneath the volcanics, were dated as Luisian by E.H. Stinemeyer (report to R.L. Hill, September 29, 1975).

Rocks of the Topanga Formation and interlayered volcanic rocks have left separation of slightly more than 2.5 km along the Benedict Canyon fault in the Santa Monica Mountains, approximately the same as separation of underlying Upper Cretaceous and Paleocene rocks. Offsets of middle Miocene rocks along the Verdugo and Eagle Rock faults and faults of the central San Fernando Valley have not been determined exactly. Middle Miocene volcanic rocks in the Pacoima Hills occur at an elevation of 1,300 feet (396 m) above sea level; and in Standard Oil Company's Woo No. 1 well (P10, plate 1), 7 km southwest of the Pacoima Hills, rocks in about the same stratigraphic position occur at a depth of 7794 feet (2340 m) below sea level. In the Occidental core hole (P6), 3.7 km west of the Pacoima Hills, sedimentary rocks of Lusian age, probably about the same age as the volcanics, occur at a depth of 7250 feet (2175 m) below sea level. This suggests that 2,500-3,000 meters of vertical offset of middle Miocene rocks has occurred along the Verdugo fault in the vicinity of the Pacoima Hills. A small outcrop of sandstone in basement rocks just north of the Eagle Rock fault near its eastern end may be part of the Topanga Formation; the rock is similar to sandstone in conglomerate-breccia terrane south of the fault; its presence suggests that lateral displacement along the Eagle Rock fault may not be large.

In the area just to the west of the study area (secs. 7 and 18, T1S, R14W, SBM), H.R. Lang and R.S. Dreesen have estimated that the nodular shale (Division E) of the Miocene - Pliocene marine succession has left slip along the Hollywood fault zone of between 2700 feet (810 m) and 11,000 feet (3300 m) (personal communication with H.R. Lang, October 1980) [These researchers consider the nodular shale to be uppermost Topanga Formation.] This estimation is based on the rate of thickening of the Topanga Formation, dislocation of the Santa Monica anticline and other factors, derived from subsurface studies. The dip slip component of this offset is between 1500 feet (450 m) and 2400 feet (720 m), down on the south side of the Hollywood fault, according to Lang and Dreesen.

4. Upper Miocene and lowest Pliocene rocks. Clastic marine sedimentary rocks of late Miocene age, which lie with angular unconformity on older rocks, are exposed in the study area around the perimeter of the San Fernando Valley (except in the central and eastern Verdugo Mountains and the San Rafael Hills) and in the northern Repetto Hills and Elysian Park Hills. Such rocks, concealed by alluvium, also are common in the subsurface of the San Fernando Valley, where they have been detected in exploratory and developmental oil wells (Schnurr and Koch, 1979; and data from California Divisions of Oil and Gas and Mines and Geology).

In the Santa Monica Mountains, these rocks were assigned by Hoots (1931) to the Modelo Formation (Tm) which had been named from exposures in the Modelo Peak area of Ventura County by Eldridge and Arnold (1907). Subsequently they have been mapped accordingly by most geologists working in the Santa Monica Mountains, as well as in the

Mission and Pacoima Hills and westernmost Verdugo Mountains in the northern San Fernando Valley area (Eckis, 1934; Durrell, 1954; Hardey, 1958; Harding, 1952; Terpening, 1951; Elliott, 1951; Neuerburg, 1953; Beatie, 1958; Merifield, 1958; Oakeshott, 1958; Oakeshott, 1958; Oakeshott, editor, 1975; and others).

In the Repetto and Elysian Park Hills, and in the Silverlake area, near and within the Hollywood and Raymond fault zones, rocks of this age have been assigned to the Puente Formation (Tp) by most geologists (Woodford and others, 1954; Eaton, 1923-24, 1926; Eckis, 1934; Lamar, 1970; Soper and Grant, 1932; Stark and Thompson, 1970; Taweel, 1963; Weldon, 1955; Vandiver, 1952; and others). This usage follows the work of Eldridge and Arnold (1907), who applied the name Puente Formation to rocks exposed in the Puente Hills. Carlson (1945), however, mapped upper Miocene rocks in the Silverlake area as Modelo Fromation.

In general, the late Miocene marine sedimentary rocks consist of thick successions of clay and diatomaceous shale, siltstone, beds of massive sandstone, and very sparse (generally a thin, basal) conglomerate. The rocks generally become finer-grained up section. Woodford and others (1954) describe four members of the Puente Formation which, in general, have been accepted by geologists as the basic map units of the formation; these members are, from oldest to youngest: La Vida, Soquel, Yorba, and Sycamore Canyon. While mapping in the northern Reppetto Hills subsequent to Woodford and others (1954), Lamar (1961, 1970) remapped some of the rocks of the Puente Formation as Topanga Formation, but Stark and Thompson (1970) indicate by micropaleontological means that these rocks (mostly siltstone, shale and fine-grained sandstone) all are late Miocene in age and, therefore, belong to the Puente Formation. A succession of similar rocks at the southeast end of the Santa Monica Mountains was mapped as Topanga Formation by Lamar (1970, plate 1) who states (p. 19) that W.H. Holman identified Mohnian foraminifera in them; this suggests to the present writer that it is more likely that they belong to either the Puente or Modelo Formation rather than the Topanga Formation.

In the eastern Santa Monica Mountains area, Durrell (1954), based on the field work of his students (Elliott, 1951; Harding, 1952; and others), assigned the lower parts of the Modelo Formation as mapped by Hoots (1931) to the Topanga Formation. The present writer has tentatively reassigned at least some of these rocks to the Modelo Formation where they are exposed along Mulholland Drive; in this area they include a thin, gently dipping bed of conglomeratic sandstone that apparently overlies unconformably more steeply dipping rocks that contain conglomerate beds with clasts different from those in the conglomeratic sandstone. The latter clasts appear to be mostly of San Gabriel Mountains crystalline rock types, whereas the more steeply dipping rocks contain abundant pebbles and cobbles of slate (from the Santa Monica Formation) and quartzite and metavolcanics. [It is possible that some of the oldest beds of the Modelo Formation in the study area are latest middle Miocene (upper Luisian) in age, as they are known to be in the Thousand Oaks and Santa Susana Mountains areas.] In the Mission Hills and the foothills of the San Gabriel Mountains to the east, the Towsley Formation of latest Miocene and early Pliocene age overlies the Modelo Formation.

The upper Miocene rocks are intensely deformed where they are exposed in the general vicinity of the Hollywood and Raymond faults of the Santa Monica - Hollywood - Raymond fault system in the Glassell Park - Highland Park area. In this area, the rocks are so complexly folded and faulted that the geologic interpretation of the area varies considerably among workers (Baudino, 1934; Taweel, 1963; Lamar, 1961, 1970; Stark and Thompson, 1970; and plate 1 of the present report). Yerkes and others (1965, p. A51) imply that 3,500-4,000 feet (1,070-1,220 m) of stratigraphic separation of upper Miocene rocks, upthrown on the north side of the fault system, just west of the Los Angeles River, is greater than maximum separation along the system to the east. These authors also state (p. A51) that farther to the west, in the Beverly Hills area, stratigraphic separation of the base of upper Miocene rocks along the fault system is 6,500 feet (1,980 m), upthrown on the north.

Rocks of probable late Miocene age are also intensely deformed in the immediate vicinity of the Benedict Canyon fault zone in the Santa Monica Mountains and rocks of known late Miocene age north of the Mission Hills fault in the Mission Hills are steeply folded within the Mission Hills anticline (Oakeshott, 1958; Merifield, 1958; Barrows and others, 1975). They are also folded in the area east of the Hansen Dam (Beatie, 1958, and plate 1 herein). Structure section A-A' of Schnurr and Koch (1979) indicates that southeast of the Mission Hills the top of the upper Miocene rocks is displaced vertically downward to the south along the Haddon and closely related faults in excess of 2,000 feet (600 meters plus). Similar relationships between the Pacoima Hills and San Fernando Valley area to the southwest based on surface and subsurface data, suggest that upper Miocene rocks have been dropped downward relatively on the southwest side of the northern part of the Verdugo fault zone in excess of 6,000 feet (2,000 m plus).

5. Pliocene to mid-Quaternary rocks. Rocks of this age crop out in the northwest and southeast parts of the study area. In the northwest, rocks of this age consist of the upper part of the marine Towsley Formation of Mio-Pliocene age, the marine Pico Formation of Pliocene age and the transitional Sunshine Ranch and nonmarine Saugus Formations of Plio-Pleistocene age. On plate 1, the Towsley Formation is combined with the Pico Formation (as Ttp) and the Sunshine Ranch and Saugus Formations are combined (as TQs).

Rocks of this age are exposed in the Mission Hills and the foothills of the San Gabriel Mountains and have been encountered in exploratory and developmental oil wells in the northern and central San Fernando Valley. These rocks are within the Ventura Basin.

Rocks at a locality in the Highland Park area and at a locality in Raymond Hill have been assigned Pliocene ages tentatively, as reported by Lamar (1970, plate 1 and p. 31-33). These rocks contain assemblages of marine megafossils which are probably of Pliocene age but which could be as old as late Miocene, according to Lamar. The fossils of probable Pliocene age in the Highland Park area occur along the south edge of the Raymond fault zone. They have been assigned to the Fernando Formation by Lamar (1970). The Fernando Formation in the Los Angeles Basin is equivalent to the Pico Formation in the Ventura Basin. The marine rocks (Tfm) apparently underlie nonmarine conglomerate (Tfn) (locality 101a) which was derived from conglomerate-breccia which lies to the north. The contact between the marine and nonmarine rocks may have left separation of about 0.3 km along the Raymond fault, as shown on plate 1.

In the area of the Mission and Pacoima Hills, cross section A-A' of Schnurr and Koch (1979) shows the base of a succession of Plio-Pleistocene sediments, apparently 4,000 feet (1,200 m plus) thick, to lie at a depth of 5,500 feet (1,650 m plus) below the ground surface, just 1.6 km southwest of the Pacoima Hills where no-longer present Plio-Pleistocene rocks probably once overlay late Miocene rocks and have apparently been eroded away. These relations imply that the base of Pliocene rocks in this area has been displaced vertically across the north part of the Verdugo fault zone in excess of 2,000 to 2,500 m (figure 6 and table 1).

Yerkes and others (1965) state that the base of Pliocene rocks in the Beverly Hills area is displaced relatively upward to the north of the Santa Monica - Hollywood fault zone about 3,000 feet (915 m) whereas the base of upper Pliocene rocks unconformably transgresses the faults of the zone. Hill and others (1979c, p. B27-28), however, state that because differential subsidence occurs along a ground water barrier along the trace of the Santa Monica fault, activity extended into the late Pleistocene and that "--Holocene movement--cannot be precluded--." Cross section A-A' (figure 10) of Hill and others (1979c) also illustrates these relationships.

6. Upper Quaternary sediments (including Holocene alluvium and colluvium). Alluvial deposits of late Quaternary age are widespread in the area studied. Older alluvium (Qoa; including terrace, flood plain and alluvial fan deposits) occurs along the edge of the lowland areas and older colluvium (Qoc) occurs as small remnants on hilltops and mountain ridges. A reddish, relict paleosol developed on these deposits causes them to be resistant to erosion and thus helps to preserve them. In the lowland areas, where development has obscured geologic relationships, older soils maps of the Los Angeles region prepared by the U.S. Department

of Agriculture (Eckman and Zinn, 1917; Holmes and others, 1917; Dunn and others, 1921) were utilized on Plate 1 to separate older alluvium (Qoa, Qoc) from younger alluvium (Qal, Qf, Qsc, Qfp) and from alluvium (Qalo) slightly older than younger alluvium. [On the soils maps, soils of the Ramona series are described as developing on nonaggrading deposits whereas soils of the Hanford and Tujunga series are developing in areas of presently active alluvial deposits.] No estimate is made here of the age of the older alluvial deposits (Qoa, Qoc) except that they are probably older than 20,000 years and younger than 150,000 years. Slightly older alluvium (Qalo) could be between 10,000 and 20,000 years in age.

Modern (Holocene) alluvium (Qal, undivided) is widespread in the study area. It includes stream channel deposits (Qsc), valley fill and flood plain deposits (Qfp) and fan deposits (Qf). Modern alluvium covers most of the San Fernando Valley, including drainage courses of Big Tujunga, Pacoima and Verdugo Washes and the Los Angeles River. The combined drainage courses have carried voluminous sediment into the San Fernando Valley and down the Los Angeles River south of the east end of the Santa Monica Mountains during Holocene time, as they drain large regions of the San Gabriel, Verdugo and Santa Monica Mountains and vicinity. [Now the sediment amount is reduced considerably because of flood control measures implemented beginning in 1913 and largely developed since the early 1930's.] Alluvial fan deposits along the base of the Verdugo Mountains are included on Plate 1 with modern fan deposits (Qf) because they appear to be active, and, although the canyons feeding these deposits do not drain large areas, the slopes of the drainage areas are steep and can yield large amounts of debris during very heavy rainfall, especially after being burned over. Areas underlain by these deposits were also included with younger, non-weathered soils by Holmes and others (1917).

Both direct and indirect evidence indicate that older alluvium and colluvium has been faulted in some places, but the amount of offset of these deposits along major concealed segments of the principal faults of the area has not yet been exactly determined. Qoc appears to be offset vertically 10 m or more across a fault that lies north of the principal trace of the Verdugo fault zone at the south edge of the Verdugo Mountains near the mouth of Stough Canyon (locality 32, plate 1). Cross section H-H', plate 5C, of California Water Rights Board (1960) shows the base of water-bearing materials [the base of Qoa (?)] to be offset downward 500 feet (150 m) to the southwest along the Verdugo fault in the area of Big Tujunga Wash (locality 20, plate 1). Alluvium once-exposed at a depth of nearly 40 m (130 feet) in a sand and gravel pit (now filled) in this area is cut by minor faults of the Verdugo fault zone, as reported by California State Water Rights Board Staff (1960) and Carl Houser of Conrock. This alluvium could be Holocene in age. The base of older alluvium may be offset downward 60 m along the western segment of the Raymond fault in the vicinity of the intersection of Eagle Rock and York Boulevards (Schroter and Lockwood, 1960; Clements, 1960; Merrill, 1975). Modern alluvium appears to be faulted along the Verdugo fault zone in the Burbank area where apparent fault scarps occur in alluvial fan deposits (Qf) (locality 34, for example). Apparent fault scarps also occur in probable younger alluvium in the Hollywood and Atwater areas (localities 82, 92 and others).

TABLE I

AGE OF MOST RECENT APPARENT OFFSETS ALONG FAULTS

(Localities: "L" numbers refer to localities on plate I and in Appendix I)

I. Holocene [less than about 10,000 years]

1. Verdugo fault zone: Burbank-west Glendale area; southwest-facing scarps 2-3 m in height in alluvial fan deposits along southwest edge of Verdugo Mountains (L 31b, 34, 37 and 38).

2. Hollywood fault zone: Atwater area of City of Los Angeles; south-facing scarps 2 m in height in alluvial deposits of Los Angeles River drainage east of river channel (accompanied by offset alluvial deposits at depth, based on work of Williams and Wilder, 1971) (L 92).

3. Raymond fault zone:

a. Pasadena-San Marino; Arroyo Drive Wash is diverted left-laterally 1,400 feet (427 m) along the fault (R.L. Hill; L 110).

b. Pasadena area; well developed scarp and youthful geomorphic features now obliterated, but described by Buwalda (1940), suggest Holocene or very late pre Holocene Quaternary movement (L 106-112).

II. Latest Quaternary (probably between roughly 25,000 and 75,000 years B.P.)

1. Verdugo fault zone: Sun Valley area; minor faults in sand and gravel deposits along zone in commercial pit at 40 m level (now covered) (L 19).

2. Hollywood fault zone: Hollywood area; apparent south-facing scarps in alluvial fan deposits of latest Quaternary (probably Holocene) age and in older alluvium of late Quaternary age (L 82, 85).

3. Unnamed fault (L 66a): North Hollywood; slight, apparent, south-facing slope break in Holocene alluvium may mark the trace of an east-trending fault. [If a fault, the feature may belong in group I.]

III. Late Quaternary (probably less than roughly 100,000-150,000 years B.P.)

1. Verdugo fault zone (and Mission Hills fault):

a. Glendale area; ground water cascade, Verdugo Wash (L 43).

b. Substantial vertical displacement (up on north) along Verdugo fault zone in Sun Valley area of ground water-bearing alluvial deposits of Big Tujunga Wash and along probable continuation of fault zone to northwest (Mission Hills fault) in San Fernando area (L 3a, 8b, 9, 18a,b). [May belong in group II.]

2. Eagle Rock fault zone: basement rocks are thrust south over Topanga conglomerate - breccia with late Quaternary paleosol developed on it (L 47).

3. Northridge Hills fault zone: apparently substantial vertical displacement (up on north) of older alluvial deposits along well-developed scarp-like features (L 13-16). [May belong in group II.]

4. Benedict Canyon fault: southwest Glendale area; base of ground water-bearing alluvial deposits apparently is offset substantially (up on south along eastward continuation of fault (L 74b).

5. Raymond fault:

a. Pasadena-South Pasadena; at Raymond Hill, base of older alluvial deposits is offset a maximum of nearly 115 m downward along the south side of the fault zone (Buwalda, 1940) (L 106).

Table 1 (concluded)

b. Highland Park-Glassell Park; base of older alluvium may be displaced downward along the north side of the fault zone 60 m (L 98).

IV. <u>Middle to late Quaternary age</u> (less than 500,000 years)

Verdugo and Mission Hills fault zones: Stratigraphic separation of the base of Pliocene to middle Pleistocene Sunshine Ranch/ Saugus formations along the Verdugo-Mission Hills fault zones may be in excess of 2,000-2,500 m; similar stratigraphic separation of the uppermost part of these rocks may be 1,000 m or more (L 17b).

C. Regional tectonics and geologic history

1. Earliest structures. Perhaps the oldest tectonic feature (pre-Tertiary ?) to have affected the study area and to be related to the present fault pattern is a major fault suggested by D. M. Morton and F.K. Miller of the U.S. Geological Survey (personal communication, 1979 and 1980) that separates the basement terrane of the Verdugo Mountains, San Rafael Hills and western San Gabriel Mountains from the basement terrane of the Santa Monica Mountains and the hills across the Los Angeles River to the east of these mountains. Based on their age dating of rocks of the Transverse Ranges, these geologists believe that the two terranes are contrastingly different. In cross section B-B' by N. Smith _in_ Schnurr and Koch (1979) a fault separating these two terranes is depicted at the south edge of the central San Fernando Valley.

Since early Tertiary (Paleocene) time, the major lateral displacement of rocks in the study area has been along the Santa Monica, Hollywood and Raymond zones, according to the work of Yeats (1968), Yerkes and Campbell (1971) and others. These scientists infer that about 90 km of left-lateral slip along the Santa Monica, Hollywood, Raymond and other faults occurred during early Miocene time, separating rocks now of the Santa Monica Mountains on the northwest and rocks of the Santa Ana Mountains on the southeast.

The latter relationship is shown in Figure 4, from which can be seen that it is possible for there to have been 25 km of left separation or more of these rocks along the fault.

Thus it seems that the oldest faults of the Santa Monica-Hollywood-Raymond system may date back at least to middle Miocene time. A very prominent, steep gravity gradient along the western part of the zone (plate 2a herein) also may reflect the dominance and longevity of the fault zone. East of the Los Angeles River, however, the gravity gradient weakens and veers east-southeastward away from the Raymond fault just east of Arroyo Seco. In the Highland Park area, Stark and Thompson (1970) do not show the major vertical offset of the basement rocks occurring along the east-trending Hollywood or Raymond faults but along their Highland Park fault (see figure 4) which extends east southeasterly from near the east end of the Hollywood fault toward the south-central San Gabriel Valley. This fault, although no longer active, displaces upper Miocene rocks, according to Stark and Thompson (1970), so that its relationship to older structural features is ambiguous.

Another regional relationship shown in Figure 4, which has implications to possible middle Miocene and/or slightly older fault movement, is the terrane containing Upper Cretaceous and lower Tertiary (Paleogene) sedimentary rocks which is separated relatively abruptly from terrane to the east not containing these rocks. This northerly trending change in lithology is reasonably well defined in the Santa Monica Mountains and less well-defined in the San Fernando Valley where two exploratory wells shown on Figure 4 reached the crystalline basement floor beneath upper or middle

Miocene rocks. The contact can be inferred to be offset left laterally slightly more than 5 km along the Benedict Canyon and perhaps other faults. South of the Hollywood, Raymond and Santa Monica zones in the study region Upper Cretaceous and Paleocene rocks apparently do not occur.

2. Modern geologic history. The origin of sedimentary rocks of Late Cretaceous through early Miocene age in the study region surely seems to be unrelated to that of later sedimentary and volcanic rocks, as judged by clast content and other sedimentary features. The modern geologic history seems to have begun during middle Miocene (Luisian ?) time with deposition in a southerly and westerly direction of coarse debris of the Topanga Formation along the steep edge of the sea. This was accompanied by extrusion of volcanic flows and breccias in the western part of the study area and gradual deepening of the sea, implied by the deposition of the siltstone and shale during latest middle Miocene and late Miocene time. The volcanic episode preceded the earliest movement on the Verdugo, Mission Hills, Benedict Canyon and related faults.

3. Speculations on detachment faulting. It seems possible that at least as far back as middle Miocene time, the ancestoral San Gabriel Mountains could have yielded masses of basement rocks, perhaps as large as 5 to 10 km or more in longest dimension, that became detached from the mountains and then moved southward by sliding (gravity "faulting"). Large masses of basement rocks are thrust-faulted at very, very low angles over Plio-Pleistocene Saugus Formation in the San Gabriel Mountains north of the study area; perhaps as long ago as middle Miocene time such masses of rock could have been thrust into unstable positions, resulting in the sliding of very large detachment blocks. Part of the Verdugo Mountains

contains very brecciated basement rocks, possibly indicating that they have moved by sliding. The finding of such blocks "floating" within younger sedimentary rocks could be of great value in estimating both lateral and vertical offsets along faults and comprehending the significance of gravity faults perhaps would help to better understand the general state of activity of faults of the region. Late middle Miocene detachment faults are a primary structural feature that have been postulated to the west in the Santa Monica Mountains by Campbell and others (1966).

N. Smith, in a small-scale cross section based on geologic and geophysical data, in Schnurr and Koch (1979), show the Pacoima Hills block (including basement rocks) to be underlain by very low angle faults above a great thickness of Miocene marine sediments. implying that the block could have been implaced by gravity faulting. However, the basement rocks of the Pacoima Hills appear from geologic evidence (plate 1) to be physically connected to similar rocks of the Verdugo Mountains and it is not clear to the writer whether Smith's cross section implies also that the entire mass of the Verdugo Mountains are also underlain by younger rocks. Oliver and others (1975, p. 206) show Upper Cretaceous sedimentary rocks reaching a depth of 20,000 feet (6,000 m) below sea level between Hansen Dam and the San Gabriel Mountains. If the Verdugo Mountains are a detachment block, perhaps the Verdugo fault originated as a detachment fault, helping to explain why it has a northwesterly trend, in contrast to the easterly trend of most of the apparently active faults of the study area.

4. Marine recession. The sea reached its maximum eastern and northern extent in the Los Angeles region during late Miocene time and then began to recede. The presence of a very late Miocene or early Pliocene shoreline on basement rocks [at an elevation today of 2800 feet (840 m)] at the southwest end of the San Gabriel Mountains (Weber, 1975, on plate 2 by Barrows and others, in Oakeshott, editor, 1975) indicates that the western end of the San Gabriel Mountains had not been elevated at that time (approximately 5,000,000 years ago) and major uplift along the eastern Santa Susana, San Fernando and western Sierra Madre fault zones probably has taken place since that time.

5. Implications of drainage history. Development of the present pattern of faulting in the study area may have taken place in relatively recent time, perhaps within the last 500,000 to 1,000,000 years(?), or late Quaternary time. One clue to the recency of initiation of certain faults may lie in the implications of ancient, concealed drainages (plate 2c) that extend westward from (1) Verdugo Wash (herein named ancient Verdugo drainage), (2) Big Tujunga Wash (herein named ancient Tujunga drainage), (3) Cahuenga Pass (herein named ancient Cahuenga drainage), and (4) Los Angeles River (north of Los Feliz Boulevard). These ancient drainages (canyons or washes) were once westward continuations of presently active drainages whose trend in the San Fernando Valley is now southeasterly and southerly. The rivers from these drainages once may have flowed into the ancient Santa Clara River drainage, perhaps west-northwestward

through San Fernando Pass (elevation now 1,600 feet, 480 m) or westward through Simi Pass (elevation now 1,600 feet, 480 m) into the Simi Valley. Now they flow southward and southeastward into the Los Angeles River at the east end of the Santa Monica Mountains. [The bedrock floor of the alluvial sediments along the stretch of this river between the northeastern corner of the Santa Monica Mountains and the Hollywood fault zone actually is inclined northward, reflecting the flow direction of the ancient drainages. In other words, a drainage divide occurred not long ago in the geologic past in the vicinity of Los Feliz Boulevard, where it crosses the Los Angeles River, with only the land south of this point draining southward. Likewise, a drainage divide occurred in Verdugo Pass, with drainage north of the pass flowing west northward into the Big Tujunga Wash drainage and the drainage to the south flowing westward into ancient Verdugo drainage.] Additionally, Clements (1960) theorized that ancient Arroyo Seco flowed westward along York Boulevard from South Pasadena, explaining the substantial thickness of alluvium along the western part of the Raymond fault. If this reasoning is correct, the ancient Arroyo Seco may have flowed west-northward into the ancient drainages of the San Fernando Valley.

It is not clear when the ancient drainage pattern changed, for it appears to be offset downward considerably along the Mission Hills fault on the southeast relative to the Mission Hills and vicinity on the northwest. It is possible that the ancient drainage system could have existed as recently as during the time when the present older alluvium and colluvium of the study area was deposited. This could make the system possibly as young as 100,000 or 200,000 years old, with vertical displacement of perhaps 100 - 300 m or more on the Mission Hills and associated faults occurring since that time. Surely the faulting occurred after deposition of the nonmarine Saugus Formation ceased, perhaps 500,000 years ago, because deposits of that formation were dropped more than 300 - 500 m on the south side of the Mission Hills fault during what has been referred to as the Pasadenan Orogeny (Bailey, 1943; Bailey and Jahns, 1954; and others). [Deposits of the Saugus Formation deposited slightly above sea level now can be found along the crest of Oakridge, a westward continuation of the Santa Susana Mountains, at an elevation of nearly 3,000 feet (900 m). The Santa Susana Mountains, lie just northwest of the study area.]

During the time that the ancient drainage system existed, Verdugo Canyon apparently lay along the base of the ancient Verdugo Mountains, which even then were being uplifted relatively along the Verdugo fault. This is probably the oldest fault of the San Fernando Valley area, which is also implied by the great difference in elevation between the location of the basement surface in the Verdugo Mountains [3,000 feet (900 m) in elevation] and the bottom of the basement surface southwest of the fault in the vicinity of Verdugo Canyon [now perhaps lower than 2,000-3,000 feet (600-900 m) below sea level] (figure 7). [Based on gravity studies, Corbato (1963, p. 1) states that the basement probably occurs at depths greater than 14,000 feet (4,270 m) in the central part of the valley, but this seems too deep, because exploratory oil wells P12 and P13 apparently reach basement in the north Van Nuys area at depths below sea level of about 4,200 feet (1,280 m) and 3,100 feet (950 m) respectively.] Rocks also may have been downdropped considerably along the north side of the Benedict Canyon fault at the east end of the San Fernando Valley during post-Saugus time.

6. Latest Quaternary (Holocene) events. Relative uplift of the Verdugo Mountains along the Verdugo fault has continued into recent time as demonstrated by the scarps in Holocene alluvial fan deposits along the southwestern edge of the Verdugo Mountains. Similar relative displacement has continued along the Hollywood fault in youthful alluvial deposits of the Los Angeles River - Verdugo Wash drainage system. Geomorphic features elsewhere along the Hollywood and Raymond fault zones also indicate tectonic activity continuing into modern time. Likewise, both known and inferred structural features beneath alluvium of the San Fernando Valley area appear to be active. Subsidence along an east-trending axis in the North Hollywood area may be a function of faulting or possibly continuing development of a syncline possibly associated with faulting.

III. DISCUSSION OF INDIVIDUAL FAULTS

A. Verdugo-Eagle Rock-San Rafael fault zone

1. Verdugo segment and Mission Hills fault. In a region where individual faults cannot be traced precisely with confidence for great distances, the faults of the Verdugo zone are no exception; but what makes the Verdugo segment imposing is the apparently substantial vertical displacement along it, as implied by the uplifted basement rocks of the Verdugo Mountains and the downdropped San Fernando Valley block in the Burbank area. Apparent scarps facing southwest in alluvial fan deposits (localities 33 to 37) in the Burbank area express the most youthful disruption of the ground surface by faulting (figure 5). A linear zone of steep gravity gradient (Chapman and Chase, plate 2a, herein) is interpreted as coinciding with the fault at depth. In addition to the scarps, older colluvium (Qoc) has been displaced downward relatively on the south against basement on the north along a north branch of the Verdugo fault (locality 32). The spacing and number of scarps indicate that the width of the zone of faulting at the ground surface may be about 0.5 km at locality 37 and perhaps nearly 1.0 km in the vicinity of localities 34 and 35.

The scarps described in the previous paragraph occur about 3 km southwest of the highest part of the Verdugo Mountains [slightly higher than 3,120 feet (950 m)]and immediately to the west of an area of the San Fernando Valley where the alluvium may exceed 1,000 feet (300 m) in depth

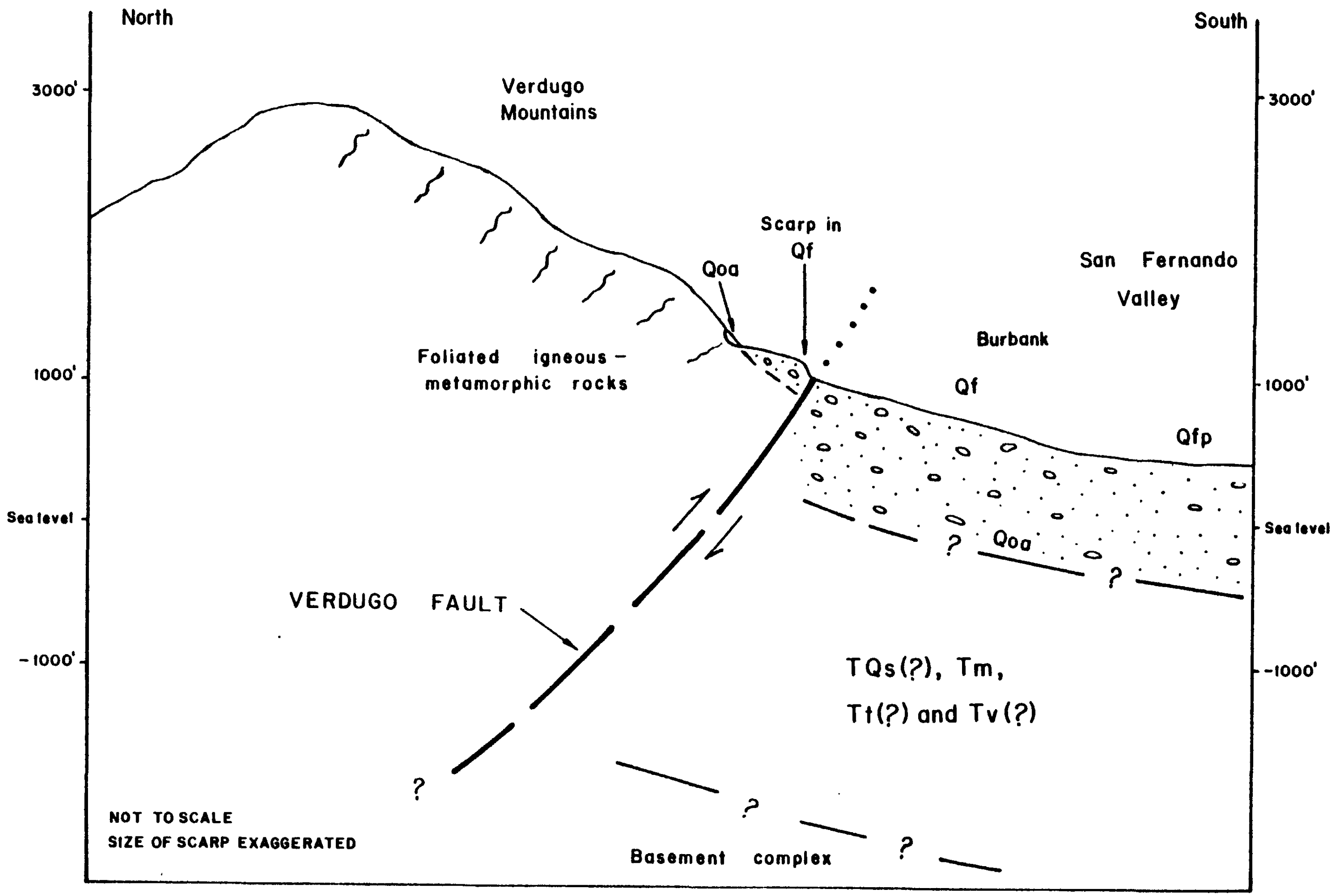


Figure 5. Pictorial cross section showing approximate relationships across Verdugo fault in Burbank area. Because of a lack of subsurface data in the area, exact relationships are not known. Dip of fault is surmised. (Symbols: Qf, Holocene alluvial fan deposits; Qfp, Holocene flood plain deposits; Qoa, Pleistocene older alluvium; TQs, Plio-Pleistocene Saugus Fm, Tm, upper Miocene Modelo Fm.; Tt and Tv, middle Miocene Topanga Fm. and volcanics, respectively.)

(Brown, 1975, p. 32; and cross section 1-1', plate 5c, of California Water Rights Board, 1960); thus the basement surface beneath the alluvium probably lies 500 feet (150 m) or more below sea level, perhaps at a depth greater than 3,500 feet (1,070 m) below the elevation of the basement at the crest of the mountains. What part of this difference in elevation is displacement caused by vertical faulting and what part is caused by other processes, especially erosion, is not known. Perhaps this relationship (figure 3) may be comparable to that involving the Elsinore fault zone in the Temescal Valley area of Riverside County, where the highest point in the Santa Ana Mountains (Santiago Peak) rises above the historically most seismically active part of the zone in the region (Weber, 1977, p. 56).

Northwest of Burbank, the Verdugo fault zone is well-expressed by a steep gravity gradient and slope breaks in alluvial fan deposits (locality 31b) which define the zone westward at least to a point near the intersection of Hollywood Way and San Fernando Road. From there, the locus of the steep gravity gradient extends northwest approximately along San Fernando Road to slightly beyond Big Tujunga Wash where it begins to curve northward and becomes obscure. There is some geologic evidence (locality 23, plate 1) that faults may diverge west-northwestward from the Verdugo fault zone in the vicinity of San Fernando Road between Lankershim Boulevard and Hollywood Way and trend toward the Northridge Hills fault. However, probable subsurface relationships between the two faults, seem to be too complex to allow projection of the Northridge Hills fault to the Verdugo fault, as interpreted from gravity, water table and elevation change data (plates 2a-2c)

In Sun Valley, the youthfulness of faulting along the zone is expressed both by an apparent ground water barrier (locality 18b, plate 1) and minor faults in Holocene (?) sand and gravel deposits that were exposed at the 40 m (130-foot) depth of a commercial sand and gravel pit (locality 19) before the pit was filled (California Water Rights Board, 1960, p. 111-7 and p. D-43 to 45; and Carl Houser, Conrock, personal communication, 1980). At more southerly arrow point of locality 19, sand and gravel exposed in a pit wall on the southwest side of the trace of the fault appears to dip 10 - 15° to the southwest, whereas northwest of the trace the dip is much gentler to the south.

A third line of evidence for relatively recent activity along the Verdugo fault in the area of locality 18 b (plate 1) is that the concealed surface upon which ground water flows steepens downward westward considerably along a line 1,000 meters long between wells 4905 (on the east) and 4895 (on the west) as determined by Thayer (1945, partly from Larue, 1943) and California Water Rights Board (1960, p. D43-44). This relationship is also shown by the water table map (plate 2b) prepared by R.B. Saul for Chapter D of this report.

A fourth line of evidence is based on the implications of structure section A-A' of Schnurr and Koch (1979, p. 5). This cross section shows that the depth to the base of alluvium near the intersection of Laurel Canyon Boulevard and Osborne Street is about 1,200 feet (366 m). This point is only 1.5 km south-southwest of the Pacoima Hills, suggesting a considerable deepening of (and probable downdropping of) the alluvium southwest of the Verdugo fault here (figure 6).

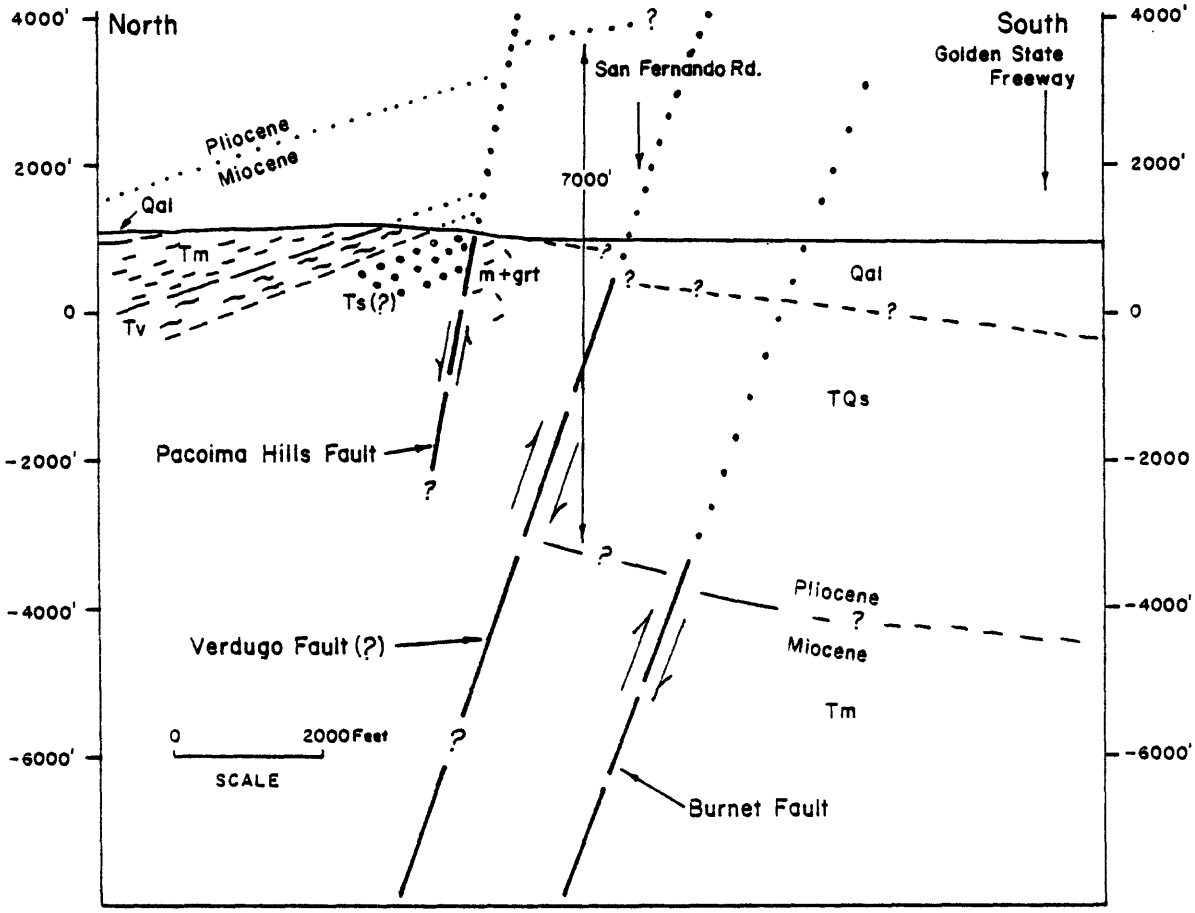


Figure 6. Schematic cross section showing approximate offset relationships among faults and rock units in the Pacoima area, where the Verdugo fault has its most northwesterly known expression and may bend westward and join the Mission Hills fault. Apparent vertical separation of contact between Miocene and Pliocene sedimentary rocks is about 7000 feet (2450 m). (Symbols: Qal, very late Quaternary older and younger alluvium; TQs, Saugus Fm (Plio-Pleistocene), Tm, Modelo Fm (late Miocene); Tv, Volcanics; Ts, Sespe Fm; m + grt, basement rocks.)

No evidence has been obtained with which the dip of the Verdugo fault in the Burbank area and to the northwest can be calculated. The only suggestion of the attitude of the fault comes from its generally curvilinear trend along the base of the mountains (concave toward the northeast) which implies a moderate dip northeastward. Another indication of the fault having a moderate dip is that foliation of the metamorphic rocks within the mountains commonly decreases in dip from moderate to steep within the mountains to gentle to moderate at their southwest edge, near the Verdugo fault (plate 1).

Northwest of the Pacoima Hills, the Verdugo fault may curve westward and join the Mission Hills fault (named by Oakeshott, 1958), as implied by Wozab (1952, figure 2). The structures respectively are similar northwest- and north-dipping reverse faults that are both known to offset ground water-bearing deposits. The principal evidence suggesting that the two structures merge is that a steep gradient in the water table seems to coincide with a line between them (plates 2b and 2c)(also shown by Wozab, 1952, and Los Angeles County Flood Control District, 1973 on maps depicting ground-water contours). Also, elevation change data (compiled by J.H. Bennett) gives a similar implication. There is also some evidence, derived from geologic ground water and elevation change data that the northwest-trending Verdugo Mountains-Pacoima Hills structural high may join the Mission Hills northwest-trending high on the northwest side of the Verdugo and Mission Hills faults (plate 2c).

Southeast of Burbank and northwest Glendale, the first observable expression of surface faulting is the most northwesterly observable part of the Eagle Rock fault - where it dips very gently northward (locality 47); this locality is about 3 km east-southeast of locality 38 -- the most southeasterly point where surface expression of the Verdugo fault coincides with a well-defined gravity anomaly. The only known expression of faulting between localities 38 and 47 is a ground water cascade, apparently on the steep, south-facing surface of the basement rocks, probably at its southwest edge (apparently just north of the principal strand of the Verdugo fault, approximately at locality 43). This cascade is described by California Water Rights Board (1960, p. III-7 and D-46). One reason that the Verdugo fault zone southeast of locality 38 is less well-defined is that southeast of that locality it may dip much more gently and thus its surface expression is more curvilinear and irregular across Verdugo Wash toward the Eagle Rock fault at locality 47 than it is to the northwest of locality 38.

In some studies, the Verdugo fault has been continued east-southeasterly from locality 38, north of the trace shown on Plate 1 herein, through a saddle, across Verdugo Wash, across a ridge and into Scholl Canyon (locality 50) (Jennings and Strand, 1969, after Byer, J.W., 1968; R.T. Frankian and Associates, 1968; Robinson and Schrenk, 1971; and Baudino, 1934). Such a continuation carries the fault within basement rocks to a point north of the Eagle Rock fault. Even though such a fault may exist, it is more likely that the principal, basement bounding segment of the Verdugo zone lies concealed approximately along the trace shown herein on Plate 1.

Offset data shown in Figure 7 indicate that vertical movement has been occurring along the Verdugo fault for a long period of geologic time.

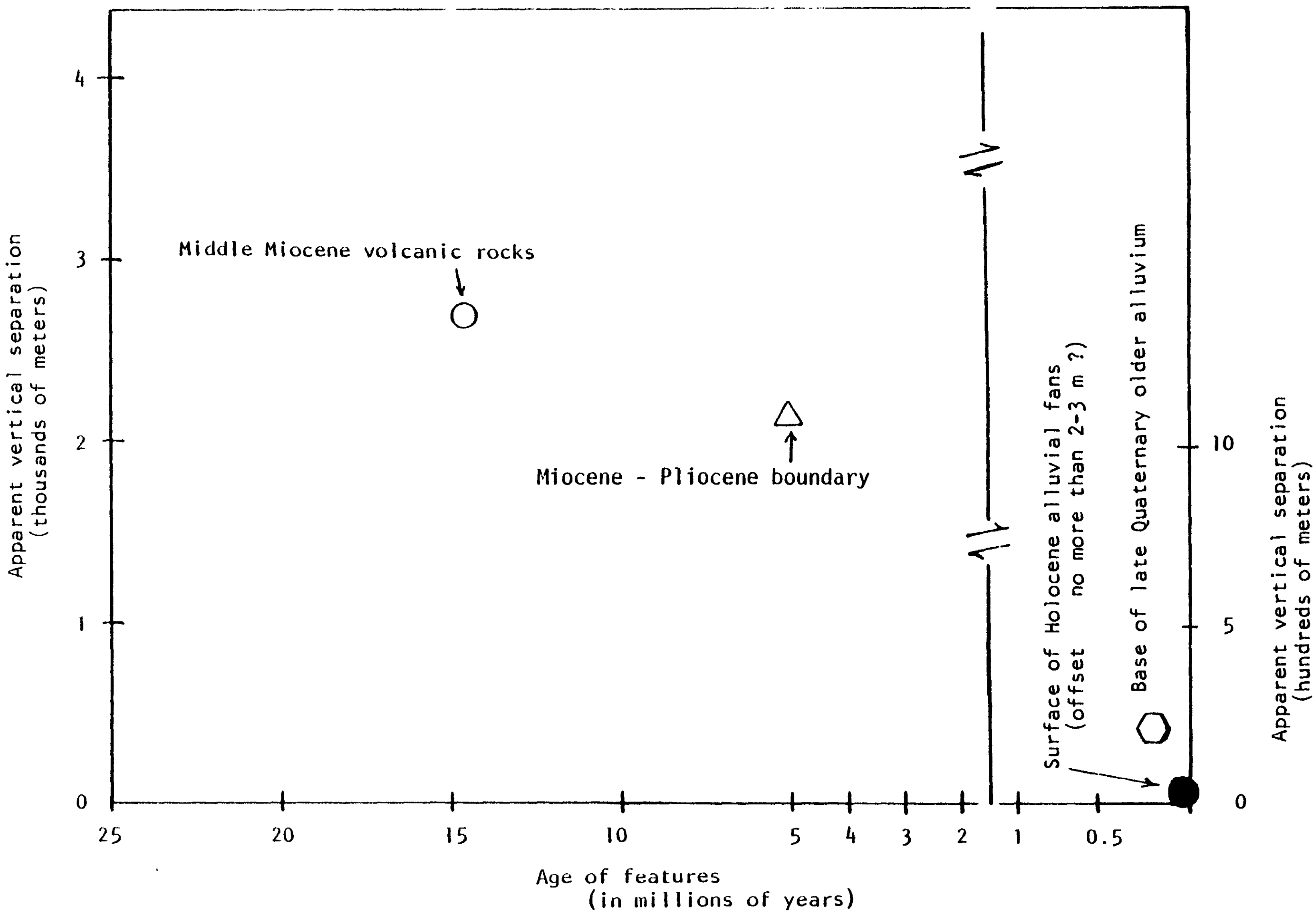


Figure 7. Diagram showing known vertical separation of rocks and other features along the Verdugo fault zone (from Appendix 1 and other parts of the report). [Vertical separation of the base of older alluvium in the Burbank area may be greater than as shown above but the amount of separation cannot be inferred from known relationships.]

2. Eagle Rock fault. The western part of the segment, Eagle Rock fault, just east of Verdugo Wash, dips very gently northward (localities 47 and 48) (figures 8 and 9). In this area, basement rocks have been emplaced over conglomerate of the Topanga Formation that has been deeply weathered during the late Quaternary time (figure 9) and possibly also over older alluvium (locality 47). The dip of the fault here ranges from about 15° to 30° north but apparently steepens to nearly vertical near its east end, about 3 km to the east (Proctor, 1975, and others). Less than 1 km west of the east end, however, the fault was observed on older (pre-development) aerial photographs by R.L. Hill (personal communication, 1979) to appear to dip moderately northward. A dip of 45° north on the fault was shown by Baudino (1934) about 0.5 km east of locality 45 (plate 1, herein).

3. San Rafael fault. The San Rafael fault, which appears to exist separately from the easternmost Eagle Rock fault, is the easternmost segment of the Verdugo-Eagle Rock-San Rafael fault system. On the northwest, the fault apparently dies out to the north of the Eagle Rock fault as a series of disjointed strands in the basement complex of the San Rafael Hills (locality 57). To the southeast of the hills, the fault may be expressed by irregular terrain in a nearly flat surface overlying terrace deposits in the vicinity of San Rafael School (locality 60a). Farther southeast, the fault is well-exposed where it separates granitic rocks from conglomerate-breccia of the Topanga Formation on the west side of Arroyo Seco (locality 60b). The fault continues east-southeast, along the north side of Grace Hill and

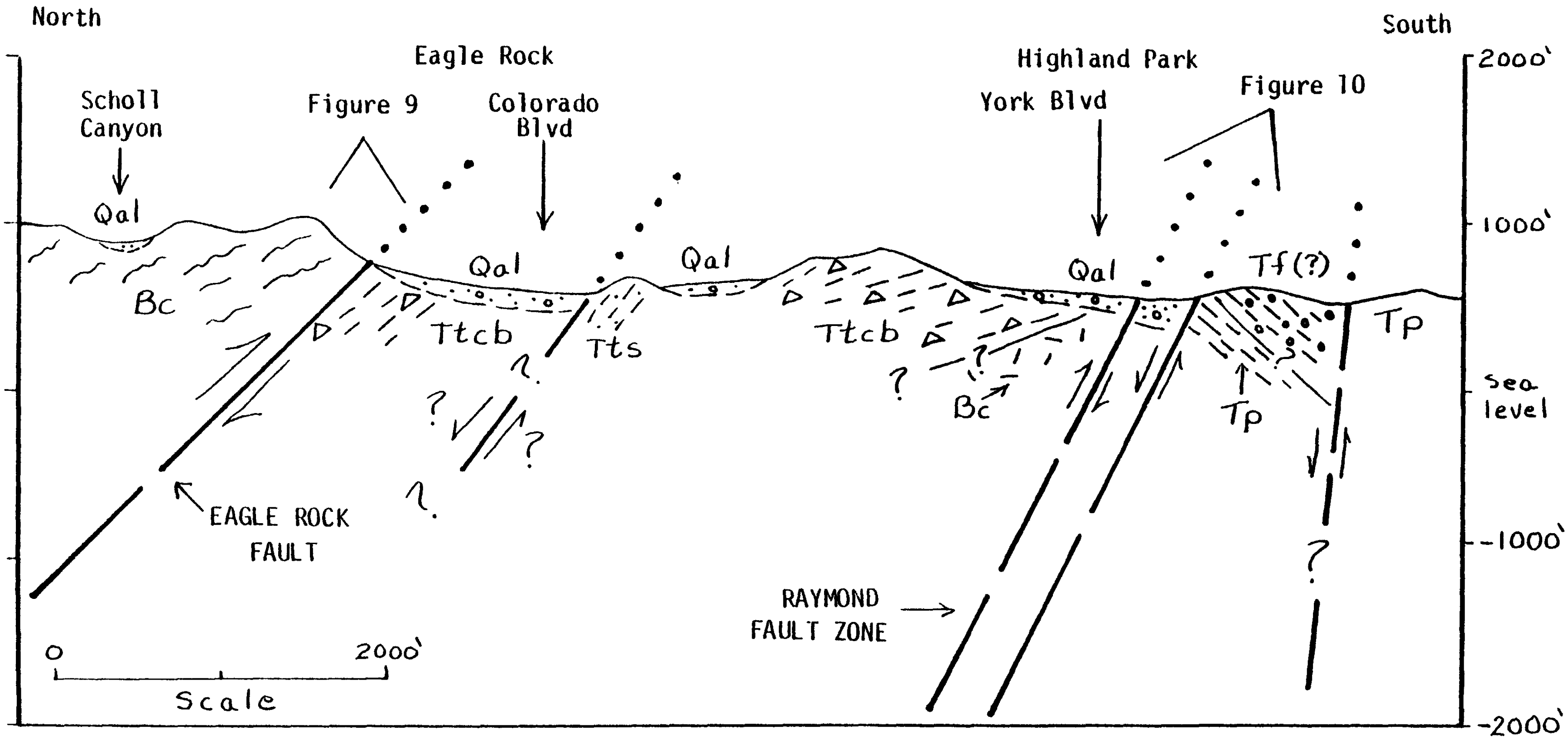


Figure 8. North to south cross section showing Eagle Rock fault and west part of Raymond fault zone in Eagle Rock - Highland Park area. Two principal faults of the Raymond fault zone here appear to define the crest of a structural high, with a block dropped down between them. [Symbols: Qal, older and younger alluvium; Tf (?) Fernando Fm (?); Tp, Puente Fm; Ttcb, conglomerate - breccia of Topanga Fm; Bc - basement complex.]

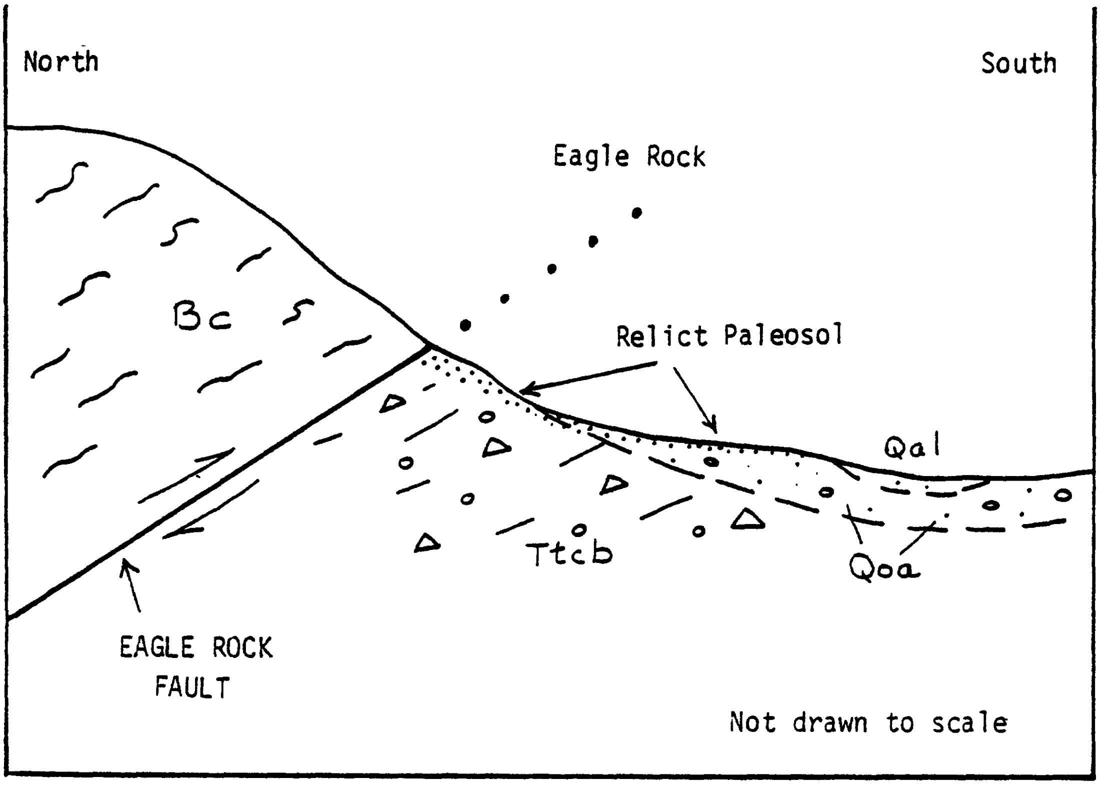


Figure 9. Pictorial cross section shows how basement rocks (Bc) are thrust south over a paleosol of late Quaternary (pre-Holocene) age developed on an erosional surface on conglomerate-breccia of the Topanga Formation (Ttcb) of middle Miocene age.

Raymond Hill, generally expressed by linear topographic lows and other features on the surface of the terrace underlain by older alluvial deposits (localities 62 and 63).

The dip of the fault, as it is expressed at localities 57, 59 and 60b, probably is very steep to vertical, similar (?) to the dip of the easternmost part of the Eagle Rock fault. The fact that the fault may be expressed along the surface of terrace deposits suggests that it has been active in late Quaternary time. At locality 65, a deflected south-trending drainage suggests left slip along the fault. An additional fault of parallel trend (locality 61) and a photo lineament north of locality 63 occur along the general trend of the San Rafael fault segment.

B. Benedict Canyon fault and related structures

The Benedict Canyon fault was first mapped by Hoots (1931, plate 16) in the Santa Monica Mountains southwest of the present map area. It has been extended northeasterly by Durrell and his students (1954) who show nearly 2.5 km of left separation of the contact between Upper Cretaceous rocks and Paleocene rocks along the fault. Mapping for the present study and other evidence indicates that the fault extends through the Universal City area and along the north side of the very eastern part of the Santa Monica Mountains (localities 68-74b). Stratigraphic relationships along the fault in the Cahuenga Pass area indicate that rocks along the north side of the fault are displaced downward relatively on the north side.

Evidence for the fault east of Universal Studios is two-fold. Geologic evidence includes a sharp photo lineament at the south edge of the Los Angeles River, and probably in bedrock, that was detected by R.B. Saul on photographs of the Fairchild Collection taken in 1928 (locality 70). Of greatest significance perhaps is a zone of steep, north-facing gravity gradients that possibly expresses two faults (localities 73 and 74a), the more southerly of which is the Benedict Canyon. The gravity data indicate that rocks along both faults are down relatively on the north, which is compatible with geologic evidence to the west in the mountains.

Geologic evidence for faulting at the east end of the mountains is sparse: north-facing faceted spurs at the very east end of the north part of the Santa Monica Mountains (south of locality 74a), although suggestive of faulting, may have been caused by erosion along the south side of the Los Angeles River. Far more significant is that in the vicinity of the abrupt bend from east to south of the Los Angeles River at the east end of the mountains (locality 74b), water-well data suggest that the bottom of the alluvial basin is displaced downward 170 m relatively on the north (California Water Rights Board, 1960, cross section M-M' on plate 5E, and pages III-7 to III-8). This locality is on the general eastward trend of the Benedict Canyon fault and coincides with the gravity gradient described previously. The fault may continue eastward from locality 74b along an apparently ancient north bank of Verdugo Wash (locality 75) toward Verdugo Canyon and the general vicinity of the Sycamore Canyon fault (locality 41a).

C. Northridge Hills fault and additional structures of the central and eastern San Fernando Valley

The San Fernando Valley is an alluvium-filled basin of nearly 900 square kilometers, of which roughly the eastern one-half is included within the study area. Within the Valley, the most prominent geologic structure observable at the ground surface is the east to east-southeast trending Northridge Hills fault. The axial trace of the San Fernando Valley syncline (figure 4) can be projected eastward concealed beneath alluvium from surface exposures in the Calabasas area toward the part of the central valley south of the Northridge Hills fault; but evidence for the existence of both the fault and the syncline diminished eastward and appears to be totally lacking in the east valley.

1. Northridge Hills fault. On the south side of the fault, strata of the Modelo Formation have been dropped relatively downward 500 to 1,000 feet (150 - 300 m), based on oil well data, according to Brown (1975, p. 38). This relation is reflected at the ground surface by a prominent south-facing break in slope, in the vicinity of the U.S. Veteran's Hospital, which is probably a modified scarp implying substantial offset of Qoa (locality 13). To the east, this scarp terminates at the western edge of Pacoima Wash.

To the east of the scarp within the younger alluvium area of the wash, only sparse, discontinuous and ambiguous surface features suggest that the zone continues eastward (localities 14-16). A minor south-facing break in slope in the Sun Valley area (locality 23) possibly represents a scarp along the eastern part of the zone, in the vicinity of a possible intersection with the Verdugo fault zone. California Water Rights Board staff (1960, p. D-25) did not find any apparent subsurface effects of faulting along the projected trace east of Sepulveda Boulevard. Their cross section F-F' (plate 5B), however, indicates that subsurface vertical offset with the south side down continues eastward to Van Nuys Boulevard (locality 15) and cross section G-G' (plate 5C) indicates that this sense of offset continues still farther eastward.

A possible fault (locality 17a) indicated by a steepening of the water table (plates 2c and 2d) may represent an east-northeastward continuation of faulting along the zone. Another possible structure (locality 22a), based on a possible steepening of the water table (plate 2b by R.B. Saul), also lies along the general eastward trend of the Northridge Hills fault. But no conclusive evidence points with certainty to the eastward continuation of the fault east of Van Nuys Boulevard.

2. Additional faults. A third feature that is shown on Plate 1 (locality 27) as a possible concealed fault extends eastward across the map from its west edge for slightly more than 17 km. This feature is defined by the pattern of contours on both the water table map prepared by R.B. Saul (plate 2b) and the gravity map of R.H. Chapman and G.W. Chase (plate 2a). The contour patterns on these maps suggest that alluvial materials and older rocks are offset downward relatively on the north

side of the feature, which, in turn, suggests that a structural block has been down-faulted (or down-folded) between this feature and the Northridge Hills fault and associated faults to the north.

Other east-trending lineaments mapped as possible faults occur to the south of the feature described above, indicated on Plate 1 by localities 28 a through c and 66a. Alluvial materials appear to be faulted downward relatively to the south along both of these features. The more northerly of these features consists of a zone of elevation changes approximately along Victory Boulevard in North Hollywood that was identified by J.H. Bennett (plate 2c). A continuation of this feature westward places it on line with a fault with a similar sense of offset mapped west of the intersection of Balboa and Burbank Boulevards in Encino by Eckis (1934, plate A) and California Water Rights Board (1960, plate 4). The latter feature is defined both by elevation change data and a possible low, south-facing break in slope in younger alluvial deposits (Qsc) in North Hollywood that can be seen on the 1901 and 1928 topographic maps of the U.S. Geological Survey that cover this area. The data of J.H. Bennett (plate 2c herein) and Plate 2 of Ledingham (1975) indicate a relatively high rate of subsidence along an east-trending axis south of this feature, in the North Hollywood area. This subsidence area appears to overlie a down-dropped block that lies north of the Benedict Canyon fault but it is not clear if a fault with a similar sense of offset occurs at the south edge of the San Fernando Valley here, north of the Benedict Cañyon fault.

In the most northerly part of the study area, east-trending structures dominate the structural pattern and appear to displace northwesterly trending structures. The most prominent of these structures, the Mission Hills fault, extends eastward concealed along the south edge of the Mission Hills. Slightly east of the hills this fault, and possibly associated features, creates a substantial ground water barrier. California Water Rights Board (1960, p. D-45) noted a drop in the water table of 250 feet (75 m) between wells 4841 (on the north) and 4842 (on the south)(locality 3a, plate 1). This relationship is affirmed by the work of R.B. Saul for this study (plate 2b). The fault may split, with one branch perhaps continuing eastward north of the Pacoima Hills and Hansen Dam and one branch bending southeastward to join the Verdugo fault (see also under "Verdugo fault").

The Pacoima Hills fault (Oakeshott, 1958) is a very short, very steeply north-dipping east-trending fault with perhaps major offset implications (locality 10). The fault places basement rocks on the south side against conglomerate, which is probably part of the Sespe Formation (Ts), on the north side (figure 6). The fault appears not to be connected with other known faults, as it is projected eastward or westward on Plate 1. A fault of Thayer (1945) to the east (locality 11a) and the Haddon fault of Schnurr and Koch (1979) to the west (locality 8a) apparently have senses of vertical displacement opposite to that of the Pacoima fault. Thayer shows youthful gravels displaced downward on the south side of his fault (locality 11a). The Haddon fault is a deep structure involved with the entrapment of oil that is projected to the surface by Schnurr and Koch. [If the Pacoima

Hills are part of a detachment (gravity) fault block, older faults within them might be expected to have no vertical roots or lateral continuity.]

A cross section drawn by N. Smith (in Schnurr and Koch, 1979) shows the basement and other rocks of the Pacoima Hills to extend downward to an elevation of nearly 5,000 feet (1,500 m) below sea level, bounded entirely by faults, and to be underlain by upper Miocene sediments that descend to about 10,000 feet (3,000 m) below sea level where they are inferred to lie on a basement floor. This cross section also shows a steep fault buried by Miocene and younger sediments at the south edge of the central San Fernando Valley. (See sections on "Basement rocks" and "Regional tectonics.")

D. Malibu Coast-Santa Monica-Hollywood-Raymond fault system

From west to east in the Los Angeles region, the Malibu Coast, Potrero, Santa Monica, Hollywood and Raymond fault zones compose major components of the system of faults and folds that separates the Transverse Ranges on the north from the Peninsular Ranges on the south. The character and recency of activity of these faults have been described in previous Division of Mines and Geology technical reports to the U.S. Geological Survey by R.L. Hill and others of the Division staff (1976, 1977, and 1979a,b). Only the parts of these faults in the present study area are discussed herein.

1. Eastern part of Hollywood fault zone. The Hollywood fault zone extends eastward into the study area along the base of the Santa Monica Mountains and continues eastward across the alluvial deposits of the Los Angeles River and Verdugo Wash in the Atwater area. To the east of these alluvial deposits, the zone apparently continues eastward within the northern Repetto Hills, to the south of the westernmost Raymond fault zone, as a complex series of faults and folds within terrane of the Puente Formation. Faults of the zone may extend eastward, concealed by the alluvium of Arroyo Seco, toward the South Pasadena area (locality 102b).

The fault zone is primarily expressed at the ground surface along the base of the Santa Monica Mountains by scarp-like features in older and younger alluvial deposits (localities 82 and 85). Additional features that appear to suggest relatively recent faulting include steeply inclined spurs at the south ends of ridges (shown partly on the map by the symbol "S"). The dip of the zone west of the Los Angeles River, based principally on attitudes of sedimentary rocks in its vicinity, may be about 60° north. A steep gravity gradient along the fault, as mapped by Chapman and Chase (plate 2a, herein), coincides with the zone at depth.

East of the Los Angeles River, the overall width of the zone is not as well expressed. In the Atwater area, a series of gently south-facing breaks in slope 2 to 3 m in height in a nearly flat surface underlain by younger and older alluvium apparently represent scarps along the principal,most recently active trace of the zone (locality 92). The breaks apparently overlie offsets in the underlying alluvial sediments of the Los Angeles River and accompanying flood plain, as shown by Williams and Wilder (1971, figures 1 and 2). These investigators indicate that sediments lying at a depth of about 35 m on the north (upthrown) side are displaced downward about 35 m on the south side along the Hollywood fault zone (as shown in figure 10, herein). The trace of this fault may continue eastward (locality 93a), entering the Repetto Hills along a linear canyon shown at locality 94.

The steep gravity gradient coinciding with the trace of the fault east of the Los Angeles River bends slightly northward at the river (locality 89) and resumes its eastward strike north of the scarps described in the previous paragraph, essentially parallel to them. The gravity gradient may coincide with a possible fault, as shown at localities 93a and 93b, that lies north of the primary trace of the zone. Structural relationships in the Los Angeles River area here are complex. No evidence was found during the study for projecting the Mt. Washington fault (locality 95) northwestward through the Hollywood fault zone and offsetting it, as was done by Lamar (1970, plate 1).

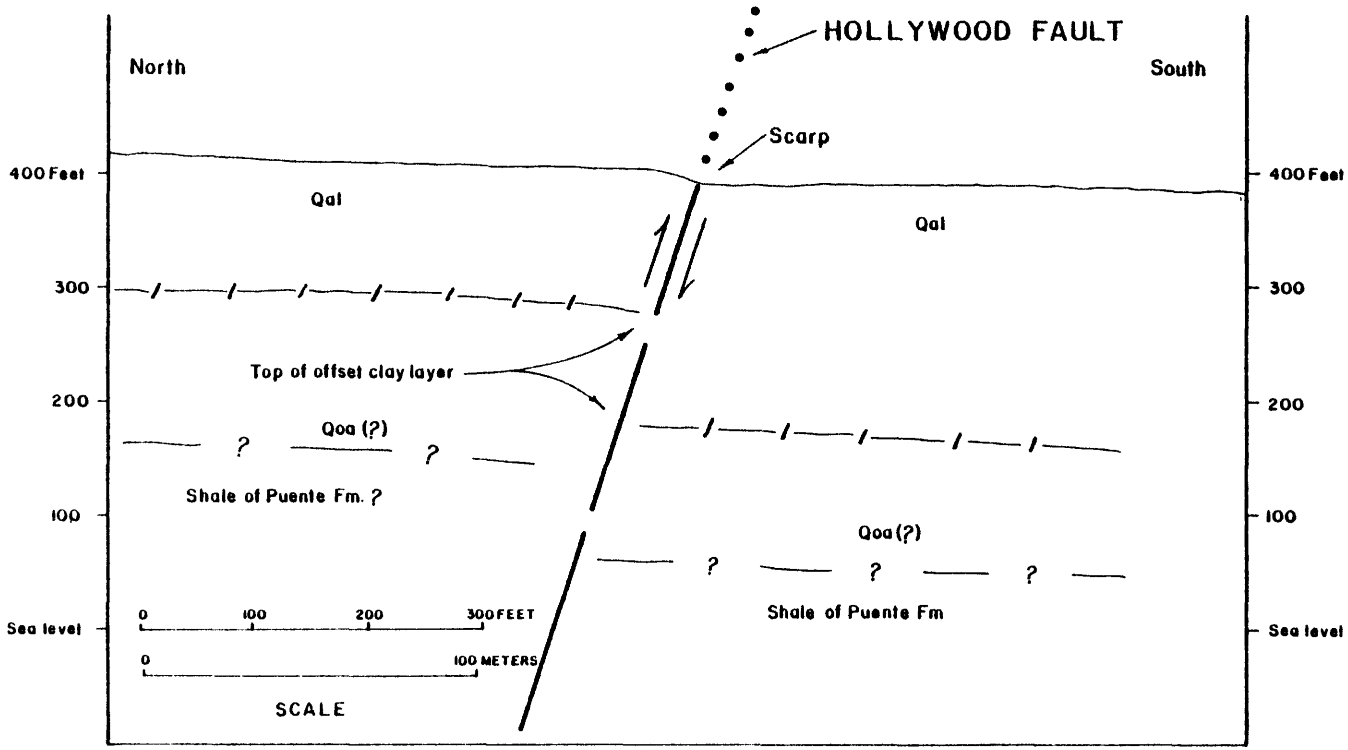


Figure 10. Schematic cross section showing offset relationships along Hollywood fault in Atwater area (plate 1, locality 92a) derived from surface mapping of scarp for this study plus map and cross sections showing offset of clay layer in alluvial deposits by Williams and Wilder (1971, figures 1 and 2) and approximate top of bedrock surface shown by water well data, including cross section M-M' of California Water Rights Board (1960). [Explanation: Qal - younger alluvium; Qoa, older alluvium].

No other geologic map of the area that shows the Mt. Washington fault shows such an offset (Baudino, 1934; Eckis, 1934; Vandiver,1952; Woodford and others, 1954, Taweel, 1963; and others).

Evidence was presented by Neuerburg (1951b) for a fault along the east side of the Santa Monica Mountains, but no evidence for such a fault was found during the present study. The Forest Lawn fault and possible faults shown at localities 81a and 81b project toward the point where the Los Angeles River crosses the Hollywood fault but no evidence for them at that point was found during this study.

Faults of the Hollywood fault zone are projected eastward on Plate 1 from the Atwater-Glassell Park area through the northern Repetto Hills along linear canyons and major lines of apparent structural discontinuity within the complexly folded and faulted shale terrane of the Puente Formation. Two major faults are projected to the south Highland Park area, just north of Arroyo Seco (locality 102b). These possible faults may join possible faults (locality 108) mapped in the South Pasadena area to the east, south of the principal trace of the Raymond fault zone.

2. Western part of the Raymond fault zone. Faults mapped during this study that extend westward from the Arroyo Seco along the general trend of the Raymond fault zone (which is well expressed east of the arroyo) are included herein with the Raymond fault zone. This contradicts the nomenclature and map depiction of faults in this area by

Lamar (1961, 1970, 1975), who, west of Arroyo Seco, mapped the York Boulevard fault along the general trend of York Boulevard. Lamar's fault, however, crosses York Boulevard west-northwesterly and diverges from the general westerly trend of the faults of the Raymond zone and accompanying structures mapped during this study in the vicinity of York Boulevard. Therefore, it seems appropriate to continue the use of the name "Raymond" for faults that extend westward from the Arroyo Seco, south of, and along the general trend of York Boulevard, to the vicinity of Verdugo Road (localities 96a to 100, plate 1).

The Raymond fault zone has been described by several workers: Eckis (1934); Buwalda (1940); and, recently, Hill and others (1976, 1977, 1979b). The principal trace of the Raymond fault is expressed from the Arroyo Seco eastward by a very prominent and sharp, south-facing break in slope (localities 106-112) in a nearly flat piedmont alluvial surface that extends across most of the Pasadena region. This scarp is accompanied by sag ponds and other geomorphic features related to continuing latest Quaternary movement. These features, described cogently first by Buwalda (1940), now are mostly obscured or have been obliterated by development, according to R.L. Hill (personal communication, 1979). Of the grosser features that still can be observed, nearly flat or slightly north-dipping parts of the piedmont surface just north of the fault that were mapped by Buwalda (1940) indicate relatively recent northward up-warping of the surface on the north side of the fault. These areas are shown on Plate 1 (dotted lines with symbol "U"). [Older alluvial deposits and their base on the north side of the San Fernando fault zone also are tilted upward (Weber, 1975, p. 91).]

The well-developed scarp marking the trace of the Raymond fault zone east of Arroyo Seco is not accompanied by a gravity anomaly. The profound gravity anomaly accompanying the Hollywood fault zone to the west in the Hollywood area, as mapped by R.H. Chapman and G.W. Chase (plate 2a, herein), seems to veer southeastward in the Highland Park area (plate 2c), away from the easterly trend of the Hollywood and Raymond fault zones. The southeastward trend of the gravity gradient somewhat follows the path of the Highland Park fault, as mapped by Stark and Thompson (1970), along which they show in cross section the basement surface displaced nearly 600 meters downward relatively on the southwest, just south of the westernmost expression of the Raymond fault (figure 11, herein). Cal-Trans drill hole data in the vicinity of the Raymond fault zone east of the Arroyo Seco show very little offset of the basement surface along the fault (from notes of R.L. Hill).

The surface evidence for relatively recent (latest Quaternary) activity along the Raymond fault zone west of Arroyo Seco is not as convincing as it is to the east. Although the zone seems to be well expressed 1.5 km west of the arroyo as two nearly parallel faults that bound a narrow graben (locality 100), Proctor (1975) reports that holes drilled by a consultant in the vicinity of Luther Burbank Junior High School (locality 104) did not yield evidence suggesting youthful faulting. Still farther west (locality 98), in the vicinity of the Sparkletts Water Company facility, logs from drill holes for water wells indicate that alluvium (including Qoa) may be displaced relatively 60 m downward on the north side of the principal fault of the zone (Merrill, 1975, p. 17-23). Similar relationships in the same area are shown in cross section A-A' of Schroter and Lockwood, Inc. (1960). Cross section S-S' (on plate 5H) of California Water Rights Board (1960) shows alluvium east of the Sparkletts facility in the vicinity of the fault zone to be relatively deep, suggesting a similar offset relationship.

Further evidence of offset of alluvial deposits is that older alluvium exposed on the north-facing slope south of the fault dips southward and, therefore, apparently must have been faulted upward to have reached that position (locality 102a and figure 11). Older alluvium apparently overlies deformed nonmarine conglomerate that resembles Saugus or Sunshine Ranch Formation, of latest Pliocene to mid-Quaternary age, but which on Plate 1 is included with the Fernando Formation (Tf ?), after Lamar (1970, plate 1). Additional evidence of latest Quaternary movement downward on the north side of the fault is represented by a pond or slough and accompanying marshy ground that existed north of the fault before about 1920 in the vicinity of the

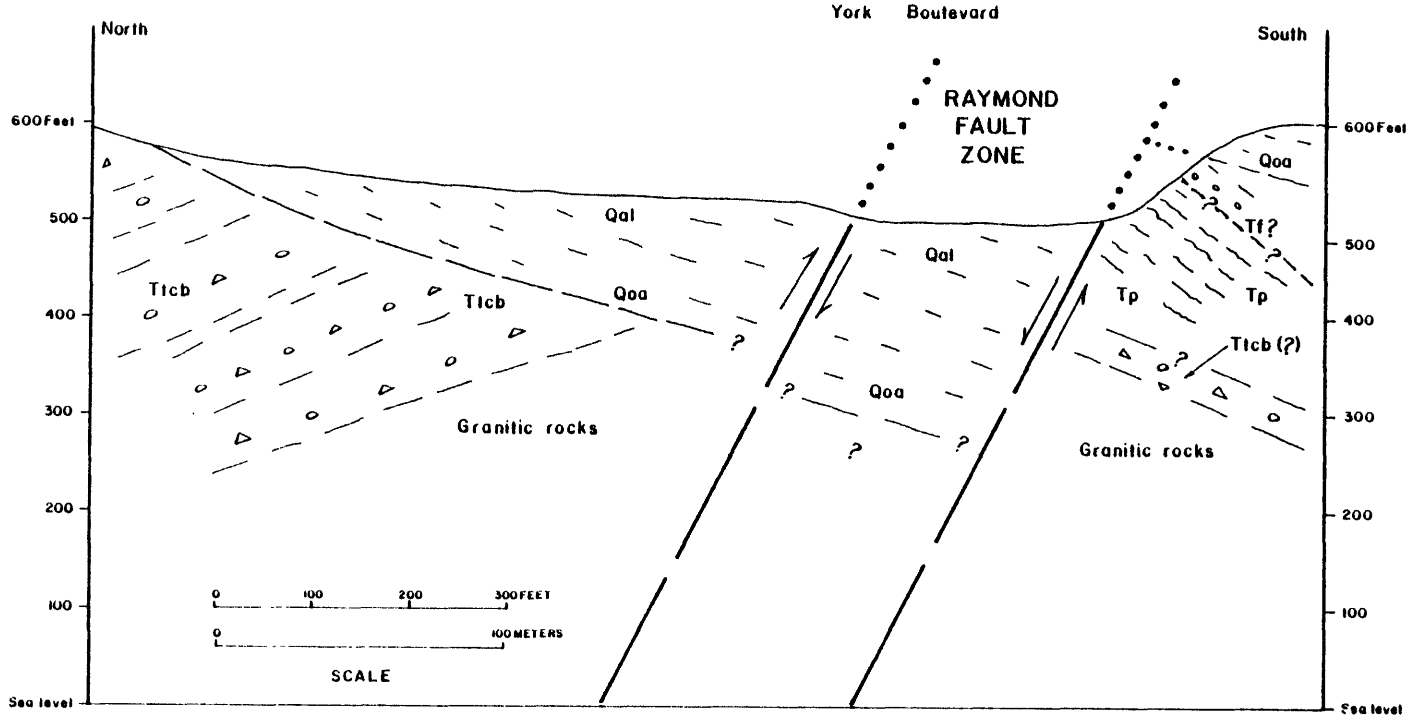


Figure 11. Schematic cross section showing geologic relationships in the vicinity of the Raymond fault in the Highland Park area. Cross section is based on field data from the present study and subsurface data from California Water Rights Board (1960, cross section S-S'), Schroter and Lockwood, Inc. (1960), Merrill (1975), and Stark and Thompson (1970). Relationships suggest that base of older alluvium may be offset vertically about 100 m upward relatively on the south with a graben-like structure developed on the north. The dip of the faults shown is surmised. (Explanation: Qal - younger alluvium; Qoa - older alluvium; Tf (?) - Fernando Fm. (?); Tp - Puente Fm.; Ttcb - conglomerate - breccia of the Topanga Fm.].

intersection of York and Eagle Rock Boulevards and marshy ground in the vicinity of Buchanan Street School (Schroter and Lockwood, Inc., 1961 and R.L. Hill, personal communication, 1979). The pond or slough probably developed because south and west flowing drainages were backed up north of north-facing fault scarps and in graben-like troughs along the fault zone, as shown on Plate 1 and in figure 12 (areas outlined with dots and shown by symbol "m").

What happens to the Raymond fault zone west of locality 98 is not clear; field evidence suggests vaguely that it may die out westward into an anticlinal fold in the vicinity of Forest Lawn. It is probable that major late Quaternary activity along the fault system through here has been transferred south to the Hollywood fault zone.

E. Additional faults

1. Sycamore Canyon fault zone. The Sycamore Canyon fault zone consists of a group of discontinuous fault segments that extends northeasterly in basement rocks in the San Rafael Hills from the vicinity of the point where Glen Oaks Boulevard crosses Verdugo Canyon to the general vicinity of upper Sycamore Canyon. The Sycamore Canyon fault was named and first mapped by John Byer (Byer, 1968; Association of Engineering Geologists, 1975, p. 5-6). Topographic lineaments (locality 42a) northeast of the area mapped for this report suggest that the zone may continue to the northeast edge of the San Rafael Hills. No evidence that the fault zone is active has been found along it in the study area. Faults of the zone exposed in basement rocks in a cut on the east

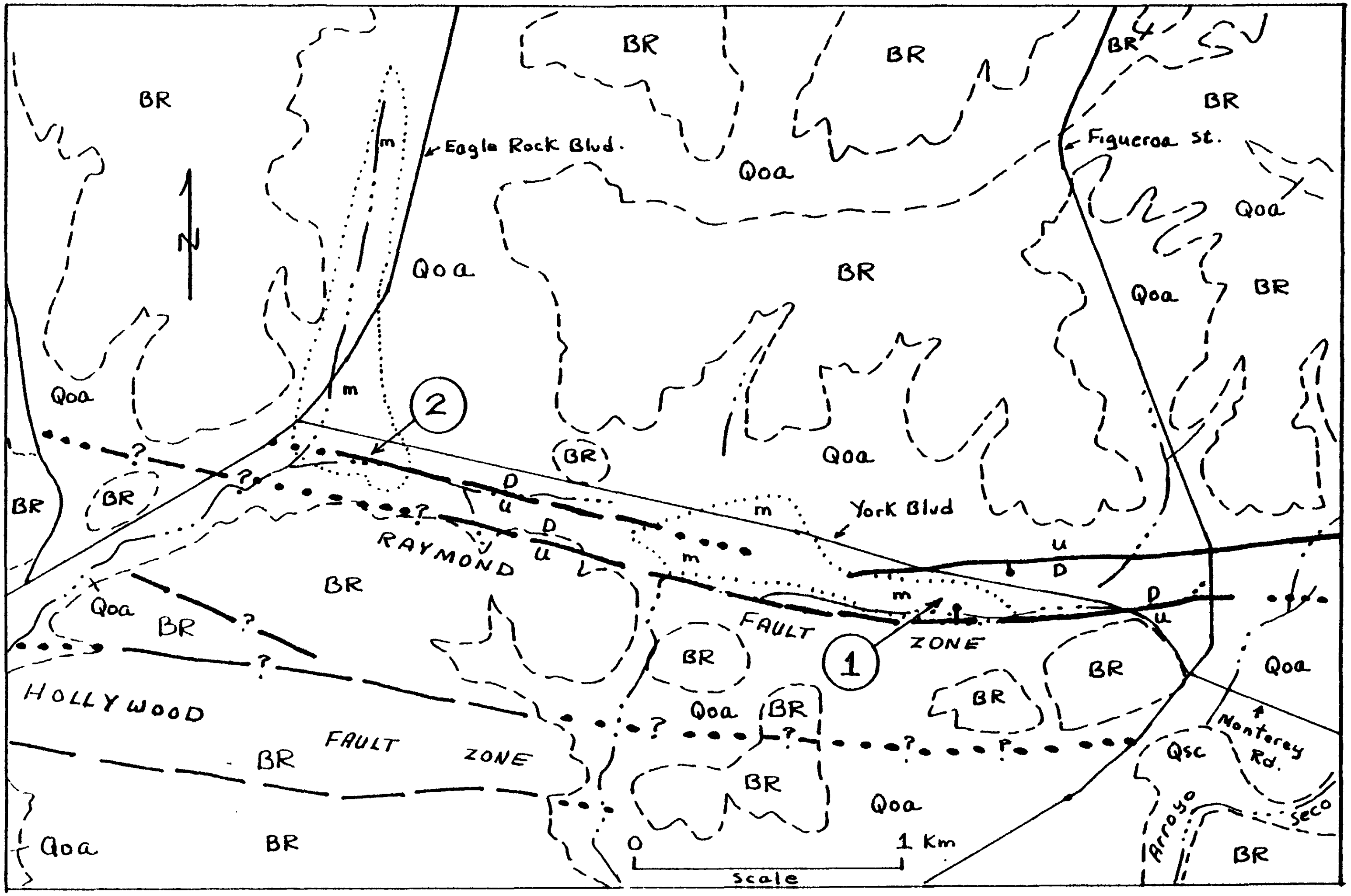


Figure 12. Simplified geologic map of Highland Park - Glassell Park area shows relationship of historic marshy ground (m) to faults of the Raymond fault zone. Presence of marshy ground suggests very late Quaternary activity along faults bordering the graben shown by locality 1 and along a fault just east-southeast of the intersection of Eagle Rock and York Boulevards (locality 2). [Explanation. Faults: U - up, D - down; ball faces in direction of scarp. Rocks: Br - bedrock; Qoa - older alluvium, with minor younger alluvium along stream courses; Qsc - stream channel deposits of Arroyo Seco. Area of marshy ground is from Schroter and Lockwood, Inc. (1960).] Also see figures 8 and 11

side of the north-trending Glendale Freeway (locality 41b), however, appear vaguely to extend upward into older alluvium (Qoa) overlying the basement rocks but to offset these deposits very slightly or not at all. [The freeway is not shown on plate 1 north of Glassell Park.] Faults of the zone constitute a slope stability hazard, however, because fault gouge, thin clayey shears and accompanying weakened rock of the zone that are exposed in steep graded cuts yield small slumps and shallow debris slides during heavy rains that result in damage to the Glendale Freeway, other roads and private residential property.

2. Griffith fault. In the north part of the easternmost Santa Monica Mountains, a moderately to steeply north-dipping reverse fault first mapped by Hoots (1931, plate 16) places granitic rocks on the north against conglomerate-breccia of the Topanga Formation on the south (locality 46). The fault, heretofore apparently unnamed, is herein named the Griffith fault, after its exposures in Griffith Park. The structure may extend eastward concealed by ground water - bearing alluvial sediments but apparently does not offset or affect in other ways these sediments or the base on which they rest (locality 77a). Eckis (1934, plate A) projected the fault eastward concealed nearly to the Eagle Rock fault.

3. Unnamed. A steep escarpment on the northwest side of the hills containing Forest Lawn Memorial Park and Adams Hill indicates that a northeast-trending fault probably occurs concealed along the base of the hills (locality 81a). The steepness of the escarpment and the fact that the lowland along its base has not been filled-in by

alluvium from Verdugo Wash and the Los Angeles River suggest that the fault probably has been active during late Quaternary time, with the north side moving downward relative to the south side. Also in the area, Converse, Davis and Associates (1974) detected lineaments on early aerial photographs that suggest faulting in the area (locality 81b).

4. Forest Lawn fault. This fault lies southeast of the fault described above, within Forest Lawn Memorial Park, striking northeasterly and separating granitic rocks on the north from marine sedimentary rocks of middle or late Miocene age on the south (Eckis, 1934; Lamar, 1970). In unpublished mapping for this study, R.L. Hill shows the fault to be slightly offset by a younger fault (as shown on plate 1, herein). Both Lamar and Hill show the fault to dip 70 - 75° southeast. There is no evidence that the fault is active.

IV DISCUSSION OF SEISMIC HAZARDS

A. Evaluating the possibility of future earthquakes in the study area by use of geologic factors.

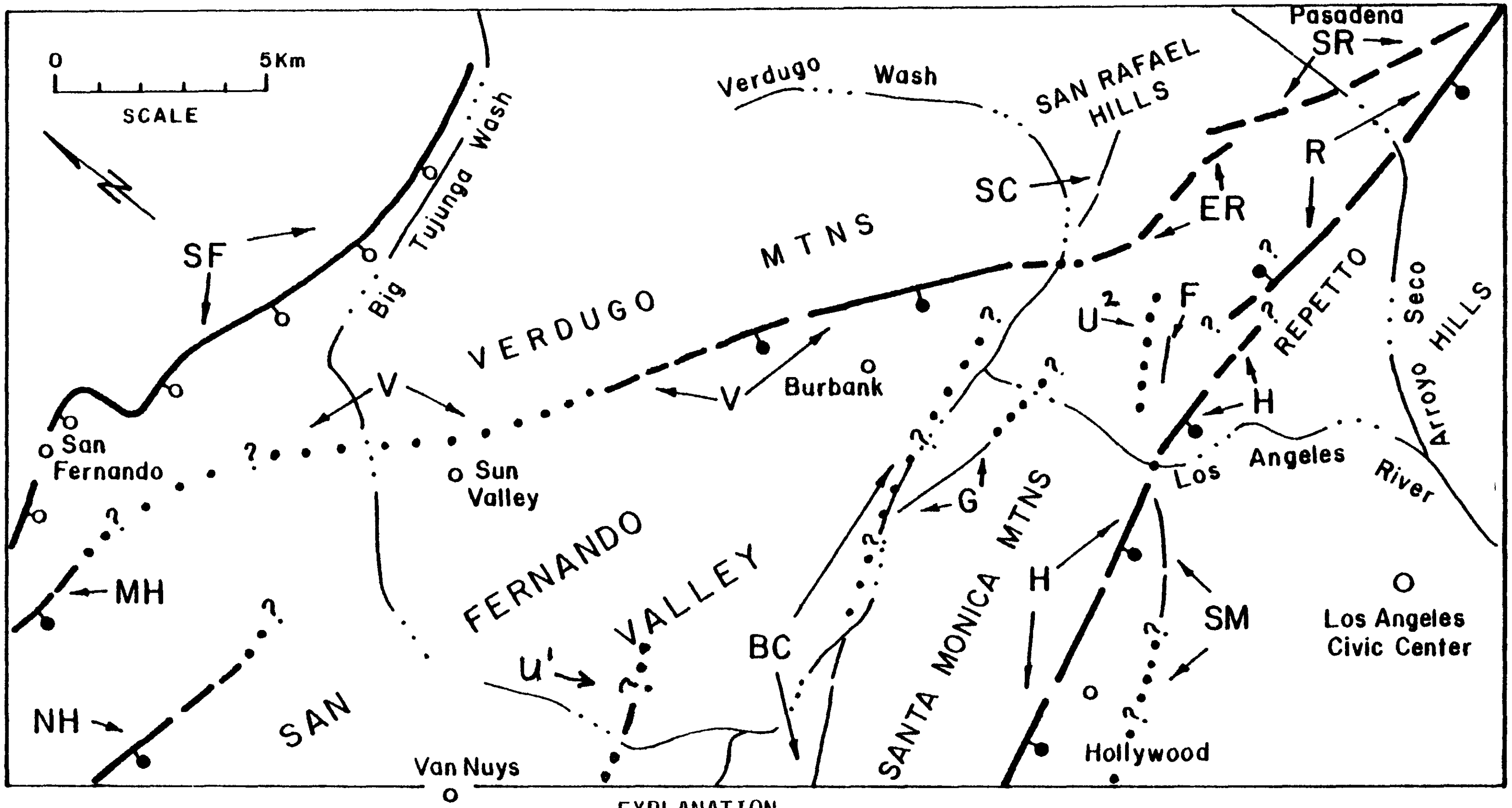
One criterion that can be used to evaluate the degree of activity of the principal faults of the study area is to compare surface features of these faults with surface features along the nearby San Fernando fault zone (plate 1 and figure 13). During the magnitude 6.5 February 9, 1971 San Fernando earthquake, this fault zone disrupted the ground surface in a very complex way westward from the mouth of Big Tujunga Canyon to the Mission Hills, a distance of about 15 km (Barrows and others, plate 2 _in_ Oakeshott, editor 1975). The San Fernando fault zone, which was essentially unrecognized by geologists before the earthquake, strikes generally eastward, dips moderately toward the north and is similar in may respects to the Verdugo - Eagle Rock - San Rafael and Hollywood - Raymond fault zones in the study area.

In addition, some of the less prominent faults of the present map area can be compared to faults of the San Fernando area away from the main fault zone that ruptured the ground during the San Fernando earthquake. The degree of similarity is not perfect, however; although many of the surface geologic and geomorphic features related to late Quaternary fault activity that are associated with the faults of the present study area are similar to those associated with the San Fernando fault zone, each zone or system naturally has its own peculiar set of surface characteristics. Nevertheless, one of the most useful lessons learned from the San Fernando earthquake was that many features that would have disclosed very late Quaternary movement along the zone prior to the actual earthquake suddenly became "visible" as a result of ground movement during the earthquake; before the earthquake most of these features apparently had been overlooked by the many geologists who had worked in the area.

Another consideration is that immediately after the San Fernando earthquake, many prominent fault breaks across alluvial areas could be traced beneath the surface in trenches only with great difficulty. In other words, before the earthquake, in order to have recognized geologically that the San Fernando fault zone was a potentially active fault zone, it would have been more fruitful to have understood the implications of the grosser geomorphic features along the zone than to have attempted by means of trenches in alluvial ground to have evaluated the activity of faults, even if their existence was known.

In general, geomorphic features of faulting along the Hollywood and Raymond fault zones are more prominent than along the Verdugo - Eagle Rock - San Rafael fault system; the former faults are part of a major fault system which is, accordingly, likely to have larger earthquakes. On the other hand, probable rapid vertical uplift of the Verdugo Mountains in late Cenozoic time implied by the steep relief and prominent scarps in Holocene alluvial fan deposits suggest that relatively large earthquakes accompanied by surface faulting may occur along the Verdugo fault zone at the base of the Verdugo Mountains.

Figure 13. Study area showing potential for ground rupture along faults; based on geologic data from plate 1 and descriptions of localities 1-111 shown on plate 1 and described in text. (Symbols represent faults as follows: BC, Benedict Canyon; ER, Eagle Rock; Fl, Forest Lawn; G, Griffith; H, Hollywood; MH, Mission Hills; NH, Northridge Hills; R, Raymond; SC, Sycamore Canyon; SF, San Fernando; SM, Santa Monica; SR, San Rafael; U^1, unnamed (locality 66a, plate 1); U^2, unnamed (localities 81a, b, plate 1); and V, Verdugo.



EXPLANATION

Segments of faults that may have surface rupture caused by moderate to large earthquakes. Solid lines denote portions of faults with well-developed scarps or apparent scarps and other geomorphic features implying relatively recent surface faulting; long-dashed lines represent faults with less well-developed features; short-dashed lines represent portions of faults with such features only minimally developed. Small circles appended to faults face in direction of scarps: open circles are appended to San Fernando fault zone which ruptured the ground surface during the February 9, 1971 San Fernando earthquake; solid circles are appended to scarps and apparent scarps on faults that are not known to have ruptured the ground in historical time.

Segments of faults that are concealed by modern alluvium along which surface features of faulting, if they ever existed, would have been obliterated.

Faults well-defined in bedrock but without features that imply recent surface faulting.

Figure 13. See opposite page for caption

Additional geologic factors that can be used to evaluate earthquake potential involve the actual or relative age of individual faults that make up major zones of faulting. As an example, the portion of the Elsinore - Whittier fault zone studied by the writer (Weber, 1977) that extends southeast for 50 km from the Santa Ana River to Wildomar in northwestern Riverside County comprises faults that may range in age from relatively modern to fairly ancient; these faults co-exist as integral, active or inactive faults ("partners") of the zone (Weber, 1977, p. 67-70). The age of individual fault strands of the Elsinore zone cannot be differentiated precisely by mapping, but it can generally be evaluated by the following differences among faults: dip (some segments dip as low as 25°, some are vertical); by their differences in relationship to other major structural elements (some fault segments seem to very closely parallel the Elsinore trough, an older structural element, and therefore seem to have originated with it; other faults along the zone, in contrast, diverge from the structural grain of the trough, cut older structural elements, and therefore seem to be relatively younger). Furthermore, the base of older alluvium seems to be only very minimally offset vertically along some apparently active faults, suggesting that these originated in fairly recent time. [If ancient faults, the base of the older alluvium would be expected to have substantially greater offset along them.]

Some characteristics of the San Gabriel fault zone (figure 4) may also be analogous to those described above for the Elsinore fault zone. For example, the nature of the San Gabriel fault zone northwest of Saugus seems to be quite different from the segment of the zone to the east-southeast, implying that the geologic history of the two segments is different; yet, there can be no argument for the present day co-existence of the two segments (Weber, 1979a, p. 66-67).

In their classification of faults of southern California with regard to their potential for seismic activity, Ziony and others (1974) indicate that the youngest deposits displaced along the Verdugo and Hollywood - Raymond faults are late Quaternary in age. In the present study, the evidence suggests that Holocene deposits have been offset along these faults.

B. Potential ground surface rupture along faults.

Because most of the study area in the vicinity of faults has been urbanized for a long time, all of the subtle effects of Holocene surface rupture along faults, if they ever existed, have been obliterated. Some more prominent features remain, however, that suggest possible recent surface rupture of the ground surface and they are described below. The relative likelihood of ground rupture along faults of the study area is symbolized in Figure 13.

Evidence accumulated during this study indicates that probable fault scarps occur in Holocene alluvial fan deposits along the Verdugo fault zone in the Burbank - Glendale area (localities 34, 37 and 38, plate 1). The scarps occur in a band up to 0.5 km wide across the fault zone, suggesting that ground rupture can be expected to occur at least within this band. To the northwest, in the Sun Valley - Pacoima area, there is no evidence that the effects of faulting have affected the present ground surface, although minor faults along the zone in alluvial deposits were observed at the 45 m (130-foot) level of a sand and gravel pit in Big Tujunga Wash in Sun Valley. These faulted sediments could be as young as Holocene because the voluminous stream flow in Big Tujunga Wash before flood control measures were implemented was capable of building thick deposits rapidly and could have quickly obliterated features of Holocene surface faulting.

Southeast of Burbank the Verdugo fault zone extends, apparently with a low northerly dip, across the Verdugo Wash to a point where it apparently joins the Eagle Rock fault. There is also no apparent evidence that surface rupture has occurred along this segment of the zone, although, as to the northwest, sedimentation along the course of Verdugo Wash probably would have obliterated the effects of surface rupture if they once existed. The Eagle Rock fault extends along the lower part of the south flank of the San Rafael Hills and if surface rupture occurred along this fault in relatively recent time, its effects easily could have been eroded away.

Faults along the eastern Hollywood and western Raymond fault zones also appear to have surface features suggestive of Holocene surface rupture. Perhaps the best evidence for such rupture occurs in the Atwater area along the eastern part of the Hollywood fault zone. Here, south-facing breacks in slope occur in flood plain deposits just east of the vicinity of the Los Angeles River. Both to the west of this locality in the Hollywood - Los Feliz area and to the east in the Glassel Park - Highland Park area, features suggesting Holocene surface rupture along the Hollywood and Raymond fault zones are more subtle, perhaps, in part, because of the complexity of faulting along the zones. East of Arroyo Seco, the well-developed scarp along the Raymond fault zone appears to have developed in latest Quaternary time (presumably into Holocene time). West of Arroyo Seco, however, development of a graben-like structure between two faults plus additional anastomosing, partly concealed and partly mappable faults, make the evaluation of the ground rupture hazard very difficult. The presence of marshy ground within the graben in the historical past implies possible relatively recent fault activity. To the west of the Los Angeles River, numerous apparent scarps occur along the Hollywood fault zone, outlining a possible zone of potential ground rupture as wide as 1 km.

No evidence was uncovered during the study to evaluate the ground rupture along the Benedict Canyon fault, although, here again, features due to Holocene ground rupture in the Santa Monica Mountains and in the alluvial area of the Los Angeles River along the north flank of the mountains are likely to have been short-lived (at one locality in the Los Angeles River area, the base of water-bearing sediments is reported to be displaced downward on the north as much as 70 m).

C. Potential ground response (including landslides).

Maximum measured ground accelerations during the San Fernando earthquake were compiled by Cloud and Hudson (1975). Their tabulations show the following maximum horizontal ground accelerations in the present study area: north San Fernando Valley, south of Mission Hills, 0.27g (one locality), vicinity of intersection of Sepulveda and Ventura Boulevard, 0.15-0.26g; North Hollywood - Griffith Park, 0.18g (two localities); Glendale, 0.19g, and 0.28g (two localities); and Hollywood area, 0.11-0.22g.

The greatest potential threat from landslides during earthquakes is in the Verdugo Mountains. If an earthquake were to occur along the Verdugo fault, causing moderate to strong groundshaking in the west Glendale - Burbank - Sun Valley area, bedrock and surficial landslides could occur. Such landslides occurred to the north in the San Gabriel Mountains and their foothills during the February 9, 1971 earthquakes (D.M. Morton _in_ Oakeshott, editor, 1975).

The landslide problem could be especially bad during earthquakes occurring during winter rainy periods when the ground is saturated. Slopes of the mountains are very steep in some places and could yield debris flows of large volume that could threaten development downslope in canyon bottoms or even at the mouths of these canyons.

Damaging shallow debris slides and flows occurred during the rains of 1978 and 1980 (Weber and others, 1978; Weber, 1980) (locality 30 and other places, plate 1, herein). Ancient bedrock landslides also were activated during these rains in the northwestern part of the mountains (see plate 1) but apparently caused no damage. Most of the ancient bedrock landslides in the mountains occur along the front of the range, in the vicinity of the Verdugo fault zone, where the gneissic rocks of the mountains are considerably fractured and weathered.

Landslides also caused damage in the San Rafael Hills during the 1978 and 1980 rains. There, shallow debris slides commonly occur in man-made cuts that expose faults. These faults consist of clay gouge, accompanying fractured and weathered gneiss or gneissic diorite which are very susceptible to slope failure (localities 41b and 42b, plate 1).

Complexly folded shale-siltstone terrane of the Repetto Hills containing faults of the Raymond and Hollywood zones in the Highland Park-Glassell Park area is also susceptible to landsliding and creep. Cracked walls, curbs and streets are common in the area. Reactivation of a bedrock landslide in highly fractured and weathered shale terrane just south of Division Street (locality 96b, plate 1) in April 1980 destroyed several houses. Strong earthquake shaking in this vicinity in wet weather probably would cause additional damaging landsliding.

Youd and others (1978) have made a study of potential ground response in the San Fernando Valley. Their Figure 3 (a small scale liquefaction potential map) shows several parts of the present study area to have moderate to high potential for liquefaction caused by strong earthquake shaking. These include the area around Hansen Dam and areas along the south edge of the San Fernando Valley.

APPENDIX 1

DESCRIPTIONS OF FAULT FEATURES AND GEOLOGIC PHENOMENA RELATED TO FAULTING AT NUMBERED LOCALITIES SHOWN ON THE ACCOMPANYING MAP, PLATE 1*

1. Because of the generally continuous strike of the San Fernando fault zone (plate 2 of Barrows and others, <u>in</u> Oakeshott, editor, 1975) it does not seem possible that the Verdugo fault could extend northwesterly into the Sylmar area as mapped by Merifield (1958) and Proctor and others (1972).

2. Two left arrows: California Water Rights Board (1960, cross section E-E', plate 5b) shows that the base of ground water-bearing sediments is offset downward about 200 feet (61 m) on the south side of the Mission Hills fault. Right arrow: an apparent, south-facing break in slope shown on older quadrangle maps of the U.S.G.S. suggests a possible scarp along the fault, as indicated.

3a. Ground water-bearing deposits may be offset vertically downward to the south of the probable trend of the Mission Hills fault toward the Verdugo fault about 250 feet (76 m), based on the depth to the water table in wells 4842 (on the north) and 4841 (on the south), as reported by California Water Rights Board (1960, p D-45). A similar relationship is indicated on plate 2b, herein, by R.B. Saul, and elevation change date from J.H. Bennett, possibly also indicating an extension of the Mission Hills fault to the southeast.

*On Plate 1, localities described herein (number 1 to 112) generally read from west to east along geologic structures starting at the most northerly part of map (with number 1 at the San Fernando fault and number 112 at the east end of the Raymond fault zone).

3b. Relatively severe ground-cracking in the area north of the Santa Rosa School (Weber, 1975, p. 85-86) suggests possible movement along a fault during the 1971 San Fernando earthquake but relationships here are very ambiguous.

4. Irregular topographic effects shown do not readily indicate a pattern related to surface faulting.

5a. Steep west-facing gradient in gravity trends almost north through this general area (Chapman and Chase, 1980; plate 2a herein). A possible fault associated with this anomaly is depicted on plate 2c herein.

5b. Interpretation of elevation change data by J.H. Bennett suggests that a fault may occur as shown. If a fault, perhaps it continues toward the possible fault shown at locality 6.

6. The linear nature of the south bank of Tujunga Wash suggests that an east-trending fault may extend through here as a general continuation of faults that occur to the west.

7. Plate 2b, herein, shows possible water table high over anticlinal fold shown by Schnurr and Koch (1979), possibly indicating a late Quaternary tectonic effect to the water table.

8a. The Haddon fault is partially projected to the surface based on sparse data provided by Schnurr and Koch (1979). See plate 2c for more generalized depiction of features in this area.

8b. Elevation change data of Jack Bennett suggest presence of Verdugo fault as indicated (see also plate 2b and 2c).

9. Strong northwest-trending gradient depicted by gravity data (plate 2a) along trend of Verdugo fault zone curves northward west of Pacoima Hills (locality 5a). This implies that the Verdugo fault dies out or is cut off by west to east trending faults. The Burnet fault is shown at depth by Schnurr and Koch

(1979) to cut off a fault that could be the most northerly segment of the Verdugo fault. There is no evidence that the Verdugo fault extends more northwesterly as shown by Merifield (1958) and Proctor and others (1972) and others.

10. Gneiss of basement complex at south edge of Pacoima Hills is separated from nonmarine conglomerate and overlying volcanic flows and breccias to the north by steeply north-dipping faults (the Pacoima Hills fault of Oakeshott, 1958). This conglomerate was mapped by Oakeshott as Topanga Formation, but it appears to the writer to be very similar to rocks of the Sespe Formation exposed in the Simi Valley and Santa Monica Mountains region. The rocks bear little resemblance to Topanga conglomerate to the east in the west end of the Verdugo Mountains.

11a. Fault that displaces gravels, based on water well data, was described by Thayer (1945) at approximately the point of the arrow. It seems reasonable that this fault has west to east trend, parallel to the general structural trend of the area, but it is not clear how the fault correlates with other faults of the area.

11b. The fault of locality 11a is in the vicinity of a sand and gravel pit of Conrock, where Carl Houser of Conrock (in personal communication with the writer and R.B. Saul) suggests that an east-trending fault extends through the bottom of Conrock's sand and gravel pit, offsetting shale at the base of the sand gravel pits.

12. Low breaks in topography occur along the trend of west-to east-trending faults known to the west (including the Pacoima Hills fault) which may extend concealed eastward in the unnamed canyon traversed by Sunland Boulevard.

13. Qoa is displaced upward on the north along a prominent, south-facing scarp on the north side of the Northridge Hills fault. The U.S. Veterans Hospital is slightly more than 100 meters north of the fault trace. The prominent scarp ends slightly east of Haskell Avenue at the west boundary of younger alluvium. (General References: Barnhart and Slosson, 1973; California Water Rights Board, 1960, p. E-24, 25). California Water Rights Board (1960, cross section D-D', plate 5A) shows that the base of water-bearing rocks may be offset downward to the south about 100 m.

14. Low, discontinuous, south-facing breaks in slope extending east from about Haskell Avenue in Qfp may mark the trace of the Northridge Hills fault. Cross section E-E' of California Water Rights Board (1960, plate 5b) shows that the base of water-bearing deposits is offset downward vertically on the south side of the fault about 130 m.

15. Subsurface effects of the Northridge Hills fault extend eastward at least as far as Van Nuys Boulevard based on data

shown in cross section F-F, Plate 5B, of California Water Rights Board (1960), with offset comparable to that at locality 14 of about 200 m. Implications of relationships with regard to offset to east nearly 2 km, as shown in cross section G-G' Plate 5C, are more vague.

16. Very low, non-oriented and discontinuous irregularities in the topography possibly could express the general eastward trend of the trace of the Northridge Hills fault.

17a. East-northeast trending groundwater barrier is depicted by water table map compiled by R.B. Saul (plate 2b herein); This barrier implies a fault in the same general location as the projection of the Burnet fault of Schnurr and Koch (1979) to the ground surface. Also, the fault may be a continuation or branch of the Northridge Hills fault.

17b. Depth of alluvium is shown to be about 1200 feet (400 m) at this locality, at the south end of structure section A-A' of Schnurr and Koch (1979); depth to base of Saugus Formation is 5400 feet (1,650 m), according to the cross section. Basement of Pacoima Hills is only slightly more than 1.5 km northwest of this point, suggesting considerable vertical downdropping during late Quaternary time of Plio-Pleistocene and younger sediments (figure 6, herein).

18a. A profile showing elevation change prepared by J. H. Bennett shows a possible subsidence trough along San Fernando Road between the two points indicated on plate 2a. relationship to faulting is not immediately apparent unless there is a connection between the Verdugo fault and the fault at locality 17a to the west. Cross section G-G' (plate 5C) of California Water Rights Board (1960) shows base of water-bearing rocks just north of Verdugo fault to reach a depth of 300 feet whereas the depth to the base of the Saugus Formation, 1½ km to the southeast, at locality 17b, may be 5400 feet. Thayer (1945, p. 10-11) stated that in 1945 the water table dropped 75 feet in elevation between wells 4904-A and 4895, even though the difference in elevation of the ground surface is only 28 feet, thus implying that the effects of faulting in the alluvial sediments created a groundwater barrier or cascade. Thayer also stated that wells 4895, 4905-A and 4905 behave similarily, implying that they are grouped southwest of the Verdugo fault.

18b. The gradient for the base of ground water-bearing materials steepens downward along a 3,000-foot east to west line across San Fernando Road, according to California Water Rights Board (1960, p. D3-44); this is based on two wells - numbered 4905 (on the east) and 4895 (on the west). In addition, there is a general steepening of the gradient between Hansen Dam and the general vicinity of locality 18b (present report), according to the report cited. Cross sections G-G' and H-H' on plate 5C of the report cited above show the general vertical component of offset along the Verdugo fault in this region, with the southwest side down relative to the northeast side; the report cited partly utilized and reaffirmed findings of Thayer (1945) who showed similar offset relationships. Plate 2b herein shows a similar relationship.

19. Beds of sand and gravel formerly exposed at the 130-foot (40 m) level in the east-facing wall of a pit once excavated commercially for sand and gravel are offset along minor faults associated with the Verdugo fault zone according to California Water Rights Board (1960, p. III-7 and p.D-43 to D-45). The faults, now covered by fill, are reportedly characterized by seams of clayey gouge. The existence of the faults, was affirmed to the writer and R.B.Saul in 1980 by Carl Houser of Conrock, which produces sand and gravel from nearby pits. This locality essentially coincides with the gravity anomaly of Chapman and Chase (1980, and plate 2a, this report) and a steepening of the water table implied by Plate 2b herein. Also suggesting relatively recent fault activity is apparent steepening of the dip of sand and gravel beds from less than 5° southward just north of the trace of the fault to 10-15° southward just south of the trace (as observed by the writer in 1980 in the deepest part of the opposite, west-facing wall of the same pit).

20. California State Water Rights Board (1960, p. D-44) described a well between the mouth of La Tuna Canyon and the Verdugo fault that at a depth of 122 feet (37 m) penetrated a 26-foot (8 m) layer of cemented gravel underlain by a 10-foot (3 m) bed of brownish

clay. Data regarding offset along the Verdugo fault of these layers, which may correlate with duricrust paleosol developed on older colluvium in the mountains to the east, have not yet been obtained in this vicinity. West-southwest of locality 20, cross section H-H' of plate 5C of California Water Rights Board (1960) shows the base of water-bearing rocks to reach a depth of nearly 700 feet (215 m) on the east side of the Verdugo fault whereas on the west side the depth is about 1200 feet (365 m), indicationg possibly more than 500 feet (150 m) of vertical displacement on the fault.

21. Low, abrupt, west-facing slope break occurs in youthful alluvium at the mouth of La Tuna Canyon along the southwest edge of the Verdugo Mountains. The break probably represents the eastern margin of south-flowing Big Tujunga Wash. If a fault does occur along the front of the mountains here, its trace is very obscure. No evidence for the La Tuna Canyon fault shown by California State Water Rights Board (1960, plate 4) and the compilation of Jennings and Strand (1969) was observed in the lower part of the canyon. Only the topographic linearity of the canyon suggests a concealed fault.

22a. Possible steepening north of water table, as shown by Saul (plate 2b herein) suggests a fault.

22b. Steepening south of water table as shown by Saul (plate 2b herein) and the elevation change data of J. H. Bennett suggests a fault (see plate 2C).

23. South-facing break in slope in apparently youthful alluvial deposits (Qsc) may mark the easternmost expression of the Northridge Hills fault or a fault along the trend of the Northridge Hills fault.

24. Severely fractured basement rocks here and at other nearby localities perhaps could represent a vestige of internal fracturing that occurred during possible detachment faulting. Minor faults in road cuts in this area range in dip from very steep to very gentle. No direct evidence of detachment faulting was discerned in the area, however (see main text).

25. Generalized fold axes determined by mapping foliation in basement complex are probably related to deformation much older than of late Cenozoic age, but similar perplexing features were also mapped by the writer (Weber, 1979a) in basement terrane to the north along the San Gabriel fault, a late Cenozoic structure.

26. Line shown on map very generally divides terrane of granitic and metamorphic rocks on the north with inclusions of schist, gneiss and marble (grt + mm) from similar rocks on the south but

without marble (grt + ma). General trend of foliation on either side of the line suggests that the line represents a significant geologic boundary between distinct metamorphic terranes.

27. A possible concealed fault (down on the north) at least 6½ km in length is suggested by a combination of gravity and groundwater data (plates 2a, 2b, and 2c, herein).

28a. A concealed fault similar to the one slightly to the north (locality 27) but down relatively to the south instead of to the north, and shorter, is defined by both groundwater data (plate 2b) and elevation changes (as compiled by J.H. Bennett). A prominent topographic high of the concealed base of valley fill (older and younger alluvium) in this vicinity (California Water Rights Board, 1960, plate 6) further suggests an upthrown block generally between faults at localities 27 and 28a.

28b. A possible fault indicated by groundwater and gravity data (plates 2a and 2b respectively) could be the continuation of a fault to the west shown at locality 28a.

28c. Gravity and possibly groundwater data (plates 2a and 2b, respectively) indicate a fault in this area.

29. South-facing break in slope, although suggestive of a fault scarp, may be just the north edge of Tujunga Wash.

30. Arrow shows path of debris flow that damaged newly constructed condominiums in March, 1978 (Weber and others, 1978). Flow was derived from existing bedrock landslide in gneissic granitic rocks which are sheared and fractured because they are relatively close to the Verdugo fault zone. Shallow debris slides also occurred elsewhere in the area in 1978 and 1980 (Weber and others, 1978; Weber, 1980).

31a. Profiles showing elevation changes compiled by J.H. Bennett suggest a fault as shown.

31b. Discontinuous, southwest-facing breaks in slope across a relatively steep surface of alluvial fan deposits (Qf) may coincide with the general northwest-trending trace of Verdugo fault zone. The trend of breaks generally coincides with the steep northwest-trending gravity gradient measured by Chapman and Chase (1980; also plate 2a herein) that is interpreted to reveal the subsurface location of the fault zone. If these breaks are scarps, their presence suggests relatively recent fault activity. Very gentle dip of foliation in basement rocks along front of mountains northeast of here suggests that the dip of the fault zone may be very gently to the northwest.

32. A fault dipping 80° south separates basement on the north from older colluvium (Qoc) on the south; vertical displacement of Qoc may exceed 10 m. This fault has been called the Verdugo fault by California Water Rights Board (1960) and others but it is

clearly a subsidiary fault of the zone. (References: California Water Rights Board, 1960, p. D-23; Association of Engineering Geologists, 1975, p. 12).

33. Low, south-facing breaks in slope in alluvial fan deposits are vaguely suggestive of fault scarps.

34. Well-defined, southwest-facing scarps in youthful alluvial sediments as determined by mapping and by photo interpretation (R.B. Saul), suggest relatively recent offsets along the Verdugo fault zone from this locality southeastward for about 5 km to locality 38. Also, this surface feature coincides with the steep gravity gradient of Chapman and Chase (1979; this report, plate 2a). Dip of foliation in basement rocks at the front of the mountains vaguely suggests that the fault zone here dips 45-60° north (see discussion in main text). (General reference: Association of Engineering Geologists, 1975).

35. Roadcut exposes Qoc on south resting in steep contact against basement to north; although minor faults and shears occur in vicinity, Qoc probably is not offset.

36a,b. R.T. Frankian and Associates (1968) mapped what they observed to be a zone of pervasive shearing and fracturing in basement rocks (between localities 36a and 36b) and called this zone the Verdugo fault. This apparent zone is interpreted for the present study to be part of the shearing and fracturing expected at the base of the upper plate of the Verdugo fault zone and at the base of the mountains, just northeast of the inferred location of the concealed, principal trace of the fault zone.

37. A series of low, southwest-facing breaks in slope in alluvial fan deposits are suggestive of fault scarps. They suggest that surface breaks along the fault zone may occur over a width of at least one-half km.

38. A southwest-facing, scarp-like feature in alluvial deposits lies above a gravity anomaly of Chapman and Chase (1979).

39. Dead Horse Canyon topographic lineaments: canyon may be site of a fault or faults (as suggested by C. Michael Scullin, personal communication, 1979). Across Verdugo Canyon to the southeast, however, there is no topographic evidence for a northwest-trending fault similar to the trend of Dead Horse Canyon; instead, known shears and faults east of Verdugo Canyon strike northeastward. The trend of foliation in the area, generally parallel to these lineaments, suggest that they may be caused by erosion along a layer of rocks that is weakly resistant to erosion.

40. Four localities with this number show occurrences of foliated granitic rocks that resemble finer-grained phases of Lowe Granodiorite in the San Gabriel Mountains north of the San Gabriel fault.

41a. Northeast-trending shears, gouge and fracturing in the basement complex make up the Sycamore Canyon fault zone. This fault was named by John Byer in 1968 (Association of Engineering Geologists, 1975, p. 5). It has been argued that a small patch of Qoa juxtaposed against a fault of zone, where exposed in a roadcut along the north side of Avonoak Terrace, is offset by movement along the fault (Association of Engineering Geologists, 1975, p. 6); the present writer and R.L. Hill examined this exposure and determined that Qoa there apparently is not offset by faulting, but may rest in buttress unconformity against basement rocks.

41b. Steeply north-dipping faults of the Sycamore Canyon zone are well-exposed within the basement complex in cuts along the Glendale Freeway. Faults may extend into but not offset or very slightly offset older alluvium on the east side of the freeway. Rocks weakened by faulting exposed in the cuts and at other localities in the area are prone to failure during winter rains (locality 42b, for example).

42a. Topographic lineaments suggest the northeast continuation of the Sycamore Canyon fault. Slope failure related to apparent fault occurred in 1980 on upper Knollwood Drive (at most easterly arrow point) (E.W. Kiessling, personal communication, July, 1980).

42b. Backyard of house on Solway Street has been damaged by sloughing from steep cut in basement complex at point where mapped fault is exposed.

43. The inferred location of the principal trace of the concealed Verdugo fault in the Verdugo Wash area is based mainly on projection of surface expressions of the fault zone from the northwest and southeast of the wash. This projection places the trace at the south edge of higher terrain lying generally to the northeast; it also fits gravity anomaly data of Chapman and Chase (1980; and plate 2a herein); and it occurs over the approximate position of a ground water cascade on the buried basement surface that has been described by California Water Rights Board (1960, p. III-7 and D-46). This cascade indicates a steepening of the basement surface that is probably a buried fault scarp.

44. Data of Chapman and Chase (1979) show a steepening of gravity contours in vicinity of the apparent trace of the fault.

45. The apparent V-shaped intersection made in plan by apparent faults in this area is enigmatic, but may represent the easternmost corner of a concealed chasm in bedrock that extends northwestward toward Burbank and beyond where relatively deep alluvium underlies the floor of the San Fernando Valley and where a gravity low is shown by Hanna and others (1974) and Chapman and Chase (1980; and plate 2a herein).

46. Prominent southwest-facing break in slope in older alluvium (Qoa) is interpreted as a possible fault scarp. The feature suggests relatively youthful movement northwest of Colorado Boulevard along a fault that is apparently truncated by a northeast-trending fault that fronts Adams Hill and adjacent hills.

47. The Eagle Rock fault is exposed in natural terrain just north of the connector lanes for the westbound Ventura Freeway to the to the northbound Glendale Freeway; there, as mapped by the writer and R.L. Hill, the fault may dip as low as 15° north and place basement over red-stained rock that is either older alluvium or a remnant of a late Quaternary paleosol developed on conglomerate-breccia of the Topanga Formation.

48. The basement complex is thrust over conglomerate-breccia of the Topanga Formation; the dip of the fault steepens eastward.

49. The Eagle Rock fault was observed by R. L. Hill in artifical exposures made during construction of the Glendale Freeway to dip 30° north and to separate basement complex above from highly weathered conglomerate of Topanga Formation or possible highly weathered older alluvium. Hill also reports that the exposures showed that the basement is highly crushed and sheared for perhaps 100 m north of the fault.

50. No evidence was discerned during preliminary phases of this study to map a fault along canyon where lineament is shown. Previous mapping (as compiled by Jennings and Strand, 1969) shows faults extending from the vicinity of the mouth of Scholl Canyon northwestward across the ridge between Sycamore Canyon and Verdugo Wash toward the Verdugo fault. No clear evidence for these faults was discerned during the present study.

51. Topographic lineaments along Sycamore and Scholl Canyons are parallel to faults of Sycamore Canyon zone but there is no evidence from the present study to show that the lineaments represent faults

52. Low, south- and north-facing breaks in slope suggest possible faulting in older alluvium south of Eagle Rock fault.

53. A prominent and steep, north-facing slope may be a scarp along a previously unidentified fault that apparently dies out fairly abruptly to the east and west of the base of the slope. Further evidence of a fault is suggested by very steep dips in rocks of the Topanga Formation directly south of this slope; dips in the area otherwise are mostly relatively gentle. Additional possible evidence that the area to the north of the slope break is down-dropped is that a water well just north of the intersection of Colorado and Eagle Rock

Boulevards penetrated 140 feet of alluvium as reported from a previous report by California Water Rights Board (1960, p. D-36).

54. Low, south-facing breaks in slope suggest possible faulting of older alluvium.

55. A thick succession of coarse conglomerate-breccia of the middle Miocene Topanga Formation consists mostly of rock debris apparently dumped to the south and southwest off steep slopes from nearby terrain underlain by granitic and metamorphic rocks into a presumably then newly-opened chasm, or basin, probably under very dynamic tectonic conditions. This event was accompanied by volcanism which is represented by volcanic flows and breccia interlayered with the conglomerate-breccia to the west in the Griffith Park and Cahuenga Pass areas of the Santa Monica Mountains.

56a. The Eagle Rock fault is reported to dip very steeply in the vicinity of Eagle Rock Reservoir (Buwalda, 1940; R.J. Proctor, <u>in</u> Association of Engineering Geologists, 1975, p. 24). The fault apparently steepens easterly from the locality 3 km to the east (locality 47) where it dips about 15° north.

56b. One strand of the Eagle Rock fault joins or is truncated by the San Rafael fault just north of the Eagle Rock. A more southerly strand may die out southeastward into the conglomerate-breccia of the Topanga Formation in the vicinity of Figueroa Street.

57. The principal trace of the steeply dipping San Rafael fault zone apparently extends northwesterly into basement terrain where it breaks up into smaller fault segments and probably dies out. This segmentation is demonstrated in artificial cuts along the road from the north end of Figueroa Street to the Scholl Canyon waste disposal site which expose intensively sheared and fractured rocks; it is also demonstrated by numerous vegetational lineaments in natural terrain. As shown on the map, the most prominent fault of the zone dips 80° S.

58. A very small outcrop of resistant sandstone (graywacke ?) just north of the Eagle Rock fault bears a resemblance to relatively nearby sandstone of the Topanga Formation south of the Eagle Rock segment; if the rocks are equivalent, the relationship suggests that if post middle Miocene lateral slip has occurred along the fault it may be relatively limited.

59. A strand of the San Rafael fault, separating conglomerate-breccia from basement complex, is poorly exposed in a slope that is partly artificially cut and partly natural along the west side of Patrician Way. The fault in the slope appears to dip steeply, as do faults of the zone to the west, across Figueroa Street.

60a. Very low, vague, south-facing slope breaks and slightly irregular topography across a very gently sloping flat surface underlain by older alluvium (Qoa) may express the trace of the San Rafael fault.

60b. The basement complex is juxtaposed against conglomerate breccia of the Topanga Formation along the San Rafael fault in the steep canyon wall on the west side of Arroyo Seco, as mapped by Lamar (1970, plate 1) and others.

61. A nearly straight, northwest-trending canyon is bounded on the southwest by contorted beds of sandstone and conglomerate breccia of the Topanga Formation. On the basis of the contorted bedding and the linearity of the canyon, a fault is inferred to lie along the bottom of the canyon. The lineament is very pronounced on oblique photographs from the Spence Collection at UCLA taken in 1923 when the land was nearly undeveloped.

62. A slight rise to the south in very gently sloping terrain underlain by older alluvium (Qoa) may have been caused by fairly recent movement along the San Rafael fault.

63. The trace of the San Rafael fault is represented by low breaks in slope and by irregular terrain on a nearly flat surface developed on the surface of older alluvium (Qoa).

64. Buwalda (1940) described essentially flat or even slightly north-dipping surface areas as being the product of upwarping along the fault.

65. The trace of the San Rafael fault is relatively well-defined by a gentle linear low in topography, as mapped by Buwalda (1940) and affirmed by Proctor (1975). Deflection of the south-flowing creek shown suggests left slip along the fault.

66a. North Hollywood area. An apparent east-northeast trending, south-facing, linear break in topography is discernible on quadrangle maps published in 1901 and 1926 by the U.S. Geological Survey, suggesting a possible fault. In addition, elevation change data developed for this study by J.H. Bennett suggest a zone of subsidence to the south (see plates 1 and 2c). These relationships suggest that youthful deposits of Tujunga Wash may be offset downward relatively to the south in recent time.

66b. Profiles showing elevation change compiled by J.H. Bennett indicate a subsidence trough along this line which may coincide with a synclinal axis.

67a. Elevation change data along the south edge of the San Fernando Valley, as interpreted by J.H. Bennett, suggests an east-trending fault in the vicinity of the Ventura Freeway.

67b. Steeply north-dipping gravity gradient suggests that two concealed faults (down on the north) may lie between the Benedict Canyon fault and the Ventura Freeway. The more northerly fault is mapped on plate 1 and both are depicted on plate 2c.

68. The principal trace of the Benedict Canyon fault extends east-northeastward from west of the study area to the crest of the central arrow point, from there it bends slightly northeastward; the bend probably reflects the dip of the fault, about 60^{o} northwestward, based on the dip of shale beds in the vicinity of the fault zone. No evidence for estimating recency of movement was found in the bedrock terrain.

69. The Benedict Canyon fault apparently extends eastward from locality 68 through a saddle developed in bedrock, as shown by the topography on the 1953 edition of the Burbank 7.5' quadrangle of the U.S. Geological Survey (which depicts the natural topography of the hilly area here before it was modified for development by Universal Studios).

70. The trace of the Benedict Canyon fault along the north side of the Santa Monica Mountains just east of Universal Studios is inferred on the basis of topographic evidence; the surface of the basement lies 2,000-2,500 m below the ground surface within about 3 km north of this projection based on figure 2 of Yerkes and others (1965). Aerial photographs taken in 1928 show a sharp line that may be the fault in the vicinity of where the arrow point.

71. This topographic lineament is in line with the Griffith fault to the east, but there is no subsurface evidence that the fault continues eastward from the Santa Monica Mountains.

72. West of locality 76, it is not clear whether the Griffith fault is truncated by the Benedict Canyon fault or whether it truncates that fault. A topographic lineament (locality 71) could represent a continuation of the Griffith fault west of the Benedict Canyon fault, but no evidence besides the linearity supports this possibility.

73. Both groundwater and gravity data suggest a fault, that is parallel and similar in apparent offset to the fault described at locality 74b. Offset along these faults could account for for the considerable deepening of the basement floor north of the easternmost Santa Monica Mountains as shown by Yerkes and others (1965, figure 2).

74a. Faceted spurs in granitic terrain along the north edge of the mountains in this vicinity suggest the presence of a concealed fault nearby to the north, although the features may have been caused by erosion along the south side of the Los Angeles River. The granitic rocks here are very sheared and fractured, also suggesting concealed faults nearby to the north.

74b. The trace of the fault coincides with a steep gravity gradient as mapped by Chapman and Chase (1980; plate 2a herein) and a groundwater anomaly mapped by R.B. Saul (plate 2b, herein). The latter anomaly reflects findings of California Water Rights Board (1960) in the vicinity of the word "Southern" as pointed to by the more westerly arrow; the Board study found that the bottom of water-bearing alluvial sediments at this locality are displaced downward relatively on the north 170 m (as shown in their cross section M-M', plate 5E, near well 3914b).

75. The north (or west) bank of Verdugo Wash trends westerly, about on line with the possible easterly projection of the Benedict Canyon fault and also somewhat on line with the Sycamore Canyon fault east of the Verdugo fault.

76. The dip of 40° north depicted on the Griffith fault (named herein) occurs near the top of a road cut and apparently steepens downward in the cut; overall, the fault appears to dip moderately to steeply north (General reference: Hoots, 1931, plate 16).

77. The Griffith fault was projected eastward concealed beyond the Los Angeles River by Eckis (1934, plate A). A slight

topographic rise mapped on plate 1 on San Fernando Road near the word "Pacific" possibly may represent the effects of faulting at the ground surface, although the rise also could easily have been caused by some vagaries of alluviation in the vicinity of the Los Angeles River. The projection of the fault trends toward the Eagle Rock fault (in the vicinity of locality 47) but no evidence known to the writer indicates that the fault actually extends eastward to that point.

78. Cross section M-M', plate 5E, of California State Water Rights Board (1960) shows that the base of the water-bearing gravels rises gradually southward between the east to south bend of the Los Angeles River and to near the point where the river crosses the Hollywood fault zone (California Water Rights Board, 1960, p. III-7 to III-8). This relationship is also reflected in the gravity contours as depicted by Chapman and Chase (1980; plate 2a of this report).

79. These very low, south-facing breaks in slope are of undetermined origin. They could have been caused by alluviation.

80. A low break in slope is of undetermined origin.

81a. A steep linear escarpment facing northwest from the hill on which Forest Lawn Memorial Park is located, and from Adams Hill, is bound on the northwest by very flat terrain which gives the appearance of having been down-dropped relatively recently by faulting. If it had not been down-dropped relatively recently it is likely that the low terrain along here would have been filled-in from the north by allivium from Verdugo Canyon and Wash. Gravity data of Chapman and Chase (1980; plate 2a, herein) also suggest downdropping to the northwest along this northeast trend.

81b. Photo lineaments recognized by Converse-Davis and Associates (1974) on two sets of older photographs suggest that a fault zone may extend approximately as shown.

82. Although the gently south-facing surface underlain by younger and older alluvium (Qf, Qoa) south of the Santa Monica Mountains here has long been obscured by cultural development, some of the still observable features of the area suggest latest Quaternary offset on faults of the Hollywood fault zone. These features include sharp, south-facing breaks in slope in the gently south-facing surface as well as prominent, steeply faceted spurs at the south end of mountain ridges bordering the surface. Evidence for estimating the dip of faults of the zone in this area was not discerned during this study; dips of bedrock closest to the faults range from about 30°-45° north, suggesting that the faults themselves may have dips within this range. The fault zone at depth through here is well-defined by a steep gravity gradient (Chapman and Chase, 1979; and plate 2a herein).

83. South-southeasterly plunging syncline in rocks of the Topanga Formation and associated volcanics does not seem to be related to modern tectonics.

84. Contact between older and younger alluvium where natural terrain is obscured by development is based on contact between older and younger soils mapped by Dunn and others (1921).

85. Terrain along the general trend of Los Feliz Boulevard and vicinity extending eastward from Western Avenue to the Los Angeles River contains many geomorphic and geologic features that are inferred to have resulted from relatively recent faulting. These features include south-facing breaks in slope on a gentle surface underlain by older alluvium and by isolated hills and hillocks along the zone which may reflect up-faulted slivers of bedrock mostly overlain by older alluvium. Among these features, the south-facing slope of a hill facing Franklin Avenue about 0.5 km east of Western Avenue is very steep, suggesting that very late Quaternary faulting has occurred along it. The south-facing spur west of the north end of Western Avenue in the vicinity of Immaculate Heart College also is very steep. As to the west at locality 82, the fault zone through here coincides with a zone of steep gravity gradient.

86a. The fault described at locality 87 and the lineament descibed at locality 54b probably extend west-southwesterly toward better defined segments of the Santa Monica fault zone as described by Hill and others (1979a, index map, p. 2; and 1979b). This lineament and the fault parallel to it to the north are projected concealed with the possibility that Olive Hill is an upfaulted block between the two faults.

86b. A topographic lineament may represent a fault of the Santa Monica zone, as it is depicted by Hill and others (1979a, index map, p. 2).

87. The principal fault of the Santa Monica fault zone separating granitic rocks on the north from rocks of the Puente Formation here appears to be truncated on the northeast by apparently younger faults that trend eastward in the vicinity of Los Feliz Boulevard beyond Los Angeles River. The overall dip of the principal fault of the Santa Monica zone may be about 60° north, based on geomorphic and geologic evidence [primarily a dip of bedding in Puente Formation (Tp) along the south edge of the fault zone].

88. The contact between granitic rocks and beds of shale and siltstone of the Puente Formation in this vicinity was mapped as a fault by Hoots (1931) and by Lamar (1970). Mapping for the present study suggests that the contact may be a fault on the west side and depositional on the south side. At least, no evidence suggests to the writer that it is continuously a fault.

89. Gravity data of Chapman and Chase (1979) in the vicinity of the Los Angeles River indicate a general eastward continuation of the zone of steep gravity gradient toward Glassell Park, but about 0.5 km north of the scarps shown at locality 92.

90. Although faults separating granitic rocks on the north from Puente Formation on the south at localities 87 (Santa Monica fault) and 91 (Forest Lawn fault) have some similar characteristics it does not seem likely that they are right laterally offset equivalents of the same fault. The direction of dip of the two faults is different and most investigators believe that long-term offset along the fault is left lateral.

91. No evidence has been found that the Forest Lawn fault is active or potentially active (also see locality 90).

92 Low, south-facing breaks in a nearly flat alluvial surface east of the Los Angeles River suggest recent offset downward relatively

to the south along the principal trace of the Hollywood fault zone in younger alluvium (Qfp) on the west and older alluvium (Qoa) on the east. In addition, Figures 1 (map) and 2 (cross section) of Williams and Wilder (1971) show alluvial sediments approximately below these scarps to be offset about 35 m, down relatively on the south, with the top of the upthrown bed having a depth beneath the ground surface of 35 m. On the other hand, there is no evidence that a northwest trending fault (locality 95) displaces the east-trending structures, as mapped by Lamar (1970, plate 1).

93a. The trace of the principal fault of the Hollywood fault zone probably lies at the south edge of a topographic prominence on which Irving Junior High School is located; the conjectural fault projected through the swale at the north edge of the prominence may be a secondary fault of the zone.

93b. The reason for a slight, south-facing break in slope is undetermined. The break is apparently natural in origin. The break occurs along the steepest gravity gradient through the area and along the line of the northly fault (?) shown at locality 93a.

94. The trace of the apparent principal fault of the Hollywood fault zone projects eastward from locality 93a toward and into the prominent canyon as shown. The steep slope

along the south side of the canyon contains a landslide, partly obscuring relationships. The fault zone appears to continue eastward as a complex series of faults and folds toward the vicinity of locality 102b. If recent fault activity diminishes from here eastward, the location of latest Quaternary fault rupturing along the Hollywood - Raymond system may step northward to the west end of the Raymond fault zone.

95. Well-documented northwest-trending Mt. Wahington fault mapped by Baudino (1934), Vandiver (1952), Lamar (1970) and others extends concealed toward the Hollywood fault zone. Lamar (1970, plate 1) shows this fault to offset right laterally nearly 1 km the principal fault of the Hollywood fault zone but evidence has not been uncovered during the present study to suggest such offset.

96a. The inferred, most northerly, west-trending fault of the Raymond fault zone may project westward as indicated on the map and die into an apparent, gentle anticlinal fold that is depicted in the vicinity of Forest Lawn.

96b. Landslide in April 1980 destroyed several houses. Slide, probably a reactivated bedrock glide, occurred in fractured and weathered shale-siltstone along south side of fault.

97. A pond or slough, now obliterated by development, existed before about 1920 in the vicinity of the intersection of Eagle Rock and York Boulevards (Schroter and Lockwood, Inc., 1960; R.L. Hill, personal communication). The depression for the pond probably was caused by relatively recent down-dropping of terrain along the north side of the Raymond fault, relative to terrain to the south. Such offset of older alluvial deposits is documented at locality 98. Marshy ground extended north from the pond for about one mile and also occurred to the east in the vicinity of Buchanan Street School, as shown on the map, probably partly within a graben developed there along the Raymond fault zone.

98. Drilling in conjunction with the Sparkletts Water Company facility indicates that older alluvium (Qoa) is offset downward about 60 m on the north side of the fault shown, according to J.D. Merrill (in Association of Engineering Geologists, 1975, p. 17-23). Merrill also indicates that north of the fault, granodiorite was reached by the drilling at a depth of about 90 m beneath conglomerate of the Topanga Formation which lies beneath the older alluvium. Similar offset relationships are inferred by cross section S-S', plate 5H of California Water Rights Board (1960); this cross section shows alluvium along the north side of the hilly terrain here to be relatively deep, suggesting relatively recent faulting. The trace of the fault here probably coincides with the topographic low as shown.

99. Conglomerate poorly exposed in a road cut (left arrow) consists of well-rounded clasts of quartzite and other dense rocks set in a matrix of clean pale gray sand; this conglomerate is distinctly different from conglomerate-breccia of the Topanga Formation north of the Raymond fault zone. The conglomerate probably is a bed within either the Puente, Repetto or Fernando formations. Steeply dipping nonmarine conglomerate to the east (right arrow) is similar to conglomerate at locality 101, suggesting left separation of about 0.3 km of this rock along the south branch of the Raymond fault. Steep north-facing slopes in the vicinity of this locality and near the "T" of the street name for "Toland Way" on the map are suggestive of fault scarps.

100. The two prominent, relatively sharp and steep linear breaks in slope mapped along the Raymond fault zone in the Highland Park area may be youthful fault scarps developed in older alluvium. The two features are apparently separated by a down-dropped block (graben) which before 1920 contained a marshy area ("m") at the west end (Schroter and Lockwood, Inc., 1960). Proctor (1975) reports, however, that geologic relationships indicated by holes drilled by a consulting firm at Luther Burbank Junior High School, to the east of the site of the marsh, did not suggest recent offsets along the fault.

101. A moderately south-dipping succession of beds of conglomerate-breccia and sandstone, which contains clasts of Topanga Formation apparently derived from north of the fault zone, is exposed in the hill shown. The rocks were mapped as marine Fernando Formation by Lamar (1970, plate 1), but they

appear to the writer to be nonmarine in origin and to resemble rocks of the Saugus or Pacoima Formations (also see locality 99 and main text).

102a. The position of nearby Qoa, where it is shown dipping 10° south, suggests that it has been uplifted to the south relatively with a sense of offset similar to that at nearby locality 98 to the west (figure 11).

102b. Possible traces of faults of the Hollywood fault zone may continue eastward across the northern Repetto Hills at least to the Highland Park area where shown. There is no firm evidence of this, however.

103. A slight, south-facing break in slope may represent the eastward continuation of the fault mapped about one-half km to the west and may extend concealed through Arroyo Seco to link with possible faults east of the wash.

104. Holes drilled by a consulting geologist at Luther Burbank Junior High School did not reveal that alluvial deposits are offset by faulting according to Proctor (1975).

105. The apparent bend of the trace of the fault "upstream" to the north in the confines of Arroyo Seco suggests a possible gentle to moderate north dip for the principal trace of the Raymond fault here (R.L. Hill, personal communication, 1979). Seismic refraction profile S-7 (figure 18S) of Chapman and Chase (1979 and herein) indicates faulting at this locality.

106. The well-developed, south-facing scarp that extends eastward from Grand Avenue gradually becomes higher, better preserved and more youthful-appearing in the area along the fault zone east of Orange Grove Avenue (as first described by Buwalda, 1940, and confirmed by the work of Proctor, 1975; R.L. Hill, personal communication, 1977-79; Borchardt and Hill, 1979; and others). In his cross section S-S', just west of Raymond Hill, Buwalda (1940) shows the base of alluvial deposits to be offset downward south of the fault about 200 feet (67 m); at Raymond Hill a similar relationship along cross section P-P' shows the base to be offset downward about 375 feet (114 m). In these cross sections, the fault is shown to dip very steeply north.

107. A Cal-Trans core hole drilled here in 1972 reached quartz diorite or diorite at a depth of 240 feet south of the Raymond fault; but several holes drilled to a depth of 250 feet slightly north of the fault encountered only Tertiary sedimentary rocks (notes of R.L. Hill; Proctor, 1975).

108. Very preliminary mapping of mostly south-facing slope breaks of moderate height in an essentially flat surface developed on older alluvium (Qoa) suggests that faults may extend westward and west-southwestward, perhaps within Arroyo Seco.

109. Main trace of the fault is exposed as a zone of shears, faults and fractures in a cut slope east of a concrete flume. Cut is below a scarp that is 8 - 9 m high east of the ravine. A fault bounding the zone on the north in the face of the cut strikes 80° west and dips 58° north; exposed fractures in the zone dip 14° - 38° north. Older gravel north of the fault zone strikes N. 50° E. and dips 20° south (from notes of R.L. Hill).

110. Arroyo Drive Wash is diverted left-laterally 1,400 feet (425 m) in a trough formed nearby along base of the scarp of the Raymond fault. Scarp is 25 m high; older gravels are exposed north of the fault (from notes of R.L. Hill).

111. A 4-foot scarplet, now nearly completely degraded, crosses the floor of the mouth of Kewen Canyon and is evidence of recent movement along the zone (Buwalda, 1940; from notes of R.L. Hill).

112. Relationahips between soils and faulting along Raymond fault zone in Lacey Park are described by Borchardt and Hill (1979).

APPENDIX 2

EXPLORATORY OIL WELLS*

1. Pacoima Petroleum and Helium, #1; 2-2N-15W.

2. Intex Oil Co., Toon 1; in Modelo Fm. to bottom, 2700; 1-2N-15W. Upper Mohnian, 1430; middle Miocene 4245-B4553.

3. Standard Oil Co., Rinaldi Core Hole #1; 4-2N-15W. B4725. No data.

4. Gulf, Carey #1; 4-2N-15W. Saugus, 3825; Sunshine Ranch 4640; Lower Pico, 6460; Repetto, 7000; Delmontian, 9600; B10, 137. Dips, 7938 to B, 50-65°.

5. Exeter-Elegrath #1; 6-2N-15W. Base Saugus, 1960; Pico, 1960-B5247.

6. Occidental, Pacoima E-H #1; 10-2N-15W. Non-diagnostic [Saugus-Sunshine Ranch-Pico (?)], 1270 - 4030; Delmontian-Mohnian, 4030-7780; Luisian, 8260-B9291. Dips 6000-B, 20-30°.

7. Standard Oil Co., Century Properties; 11-2N-15W. Modelo, B8055.

8. Standard Oil Co., University #1; 15-2N-15W. Conglomerate mostly (Saugus?) 341-1076; blue clay at 1575; 2160-B5938 mostly shale and sandy shale (Miocene 3920-5938).

9. Standard Oil Co., Coffman #1; 18-2N-15W. Continental beds (Saugus-Sunshine Ranch?), 1408 (?)-3378-?; Mohnian, 6580; B6608.

10. Standard Oil Co., Woo #1; 19-2N-15W; Saugus-Delmontian contact, 3490; Delmontian-Mohnian boundary, 4390; Basalt @ 8694; in Topanga to B9739.

11. Shell Oil Co., Andrews #1-1; 19-2N-15W. Mostly hard sand and gravel, (Saugus?), 138-3359; sand and shale, 3359-4960; conglomerate, 4960-5093 (granite boulder, 4999-5000); mostly sandstone, 5093-B6005 (Miocene).

12. Standard Oil Co., Leadwell #1; 3-1N-15W. Basement, B5066.

13. Standard Oil Co., Hazeltine #1; 14-1N-15W. Basement, B3823 (2 feet of granodiorite in core, 3821-3823).

14. Van Nuys Community Oil Co., #1; 16-1N-15W. Sand and shale, 920; "Shell," 1585; hard sand, B3858 (Miocene) (off plate 1 about 2½ miles WSW of P 13).

*Data mostly from record library of Division of Mines and Geology, courtesy of E.C. Sprotte. [Explanation: Map locality P-1 etc.; 2-2N-15W, section, township and range, S.B.M.; B4725 - depth to bottom of hole; designation of rock units and sediments in parentheses are inferred by the writer]

15. Jeffrey, Overton and Halfhill, B.J. Jeffrey #1; 13-1N-14W. Shale plus boulders, 595 and 610; sticky shale and "shell," 800; shale, 810; "hd. g.s.," 896; hard sand, 900-940; B1003. (Saugus/Sunshine Ranch Fms. (?), ? - 800; Sunshine Ranch/Saugus or Modelo Fm. (?), 810-1003.)

16. B.J. Jeffrey, #2; 7-1N-14W. Bouldery sand and gravel, 281; black clay, 281-301, "shell," 301-313; black clay 313-331; hard sand and shale, 331-861; conglomerate, B1245. (Alluvium (?), 0-281; older alluvium (?), 281-301; older alluvium or Saugus/Pacoima Fms. (?), 301-B1245).

17. Henry E. Luttge; 13-1N-14W. (Sand and gravel (?) [alluvium and Saugus Fm. (?)], 0-B1700)

18. Barnes (Continental Oil Co.) Core Hole, Burbank #1; 16-1N-14W. Sand, 0-282; sand, siltstone and shale, 282-B2342 (Miocene). Dips, 1410-2100, 16-19° north-northeasterly.

19. Barnes (Continental Oil Co.) Core Hole, Hollywood Freeway #1; 18-1N-14W. Sand, 0-284; sand and shale, 284-1800; siltstone and shale, 1800-B2995 (Miocene). [Alluvium (?), 0-284: Modelo Fm. (?) at bottom.] 22° and 27° north-northwest; 2260-2950, 30-35° northerly to north-northeasterly.

20. Continental (Merchants) Oil Co., Monterey Park 1-1; 22-1S-12W. Shale, 3780-3930; shale (50%) plus slate, 4000-4096; shale, slate (50%), sand (45%, possibly veins in slate), 4096-4228; slate, 4228-4373; slate with interbeds of quartzite (schistose metamorphic rock, with common calcite veins and abundant pyrite crystals), 4373-B4384. (off plate 1 to southeast; most easterly well plotted on figure 4)

21. Texaco-Seaboard, Park #1; 9-1S-13W. Shale plus sand (including 1-to 8-foot beds of conglomerate-breccia with quartzite clasts 40-1323; unconformity and top of weathered slate, 1323; slate, 1323-B2300 (including shale, 1373-1376) (Miocene). Dips: 18°, 515-524; 30°, 924-927.

22. Texaco-Seaboard Core Hole #5; 14-1S-13W. Sand and shale, 0-2650; conglomerate-breccia (with pebbles of hard shale or slate), 2660-2704 similar to breccia in Park #1 at 1200; slate, 2709-B2732. Dips: 280, 25°; 1220, 25°; 2000, 15°; 2363, 22°.

23. Arco Silver Lake Community #A-1; 17-1S-13W.Topanga Fm., 5714-B8054; including conglomerate (with clasts of slate and schist to 3"), 6280-6282 (Topanga Fm); fault breccia (with volcanic felsite fragments), 7139-7153. Dips: 1192-5807, 6-10°; 6510, 45°; 6604-6626, 35-40°; 7153, 50°.

CHAPTER C*

GEOPHYSICAL INVESTIGATION OF THE VERDUGO-EAGLE ROCK AND ASSOCIATED FAULTS, LOS ANGELES COUNTY, CALIFORNIA

by Roger H. Chapman and Gordon W. Chase

CONTENTS

*Modified slightly from Chapter C in semi-annual report dated March 7, 1980 (OFR 80-1 LA), p. C1-C18.

INTRODUCTION

The present report concludes a geophysical study of the northern Los Angeles region by the writers. This study is one of a series of studies of various aspects of faulting in the region initiated and principally coordinated by R.L. Hill (1976, 1977, 1979a,b). The geophysical study mostly has consisted of a series of north-trending gravity traverses across the largely east-trending faults of the northern Los Angeles region. The study was done in two parts: the first part was directed at the system made up of the Santa Monica, Hollywood and Raymond fault zones; the second part was directed at the concomitant Verdugo, Eagle Rock and San Rafael fault zones and the Benedict Canyon fault. The first part of the study resulted in a report and accompanying Bouguer gravity map of the region stretching from Santa Monica to Arcadia (Chapman and Chase, 1979). The second part of the study consists of a Bouguer gravity map (plate 2a herein) that covers the eastern San Fernando Valley and overlaps the part of the first map in the east Hollywood-Highland Park area.

Data gathered from the traverses made by the writers and their assistants for the first map were supplemented by the work of C.E. Corbato, T.H. McCulloh, A.R. Sanford and Forest Lawn Comapny; and for the second map (plate 2a herein) the writer's data were supplemented by the work of C.E. Corbato (1960, 1963). In the reports accompanying both gravity maps the implications if aeromagnetic data from maps by G.E. Andreason and others (1964a,b) are discussed. Also, a series of seismic traverses were made across the Raymond fault for the first map.

GRAVITY DATA

Seven (7) new gravity traverses were made for this investigation in addition to the extensions of two earlier lines. New lines are GV1-GV5, GV7 and GV8; lines GV6 and G4x are extensions of older lines G3 and G4, respectively, all of which are shown on Plate 2a. Locations of gravity traverses and gravity data from other sources also are shown on Plate 2a. The other gravity stations shown on Plate 2a are part of a data set prepared by C.E. Corbato (1963). These stations were recalculated previously by Shawn Biehler (written communication, 1979) and data from them were included in the compilation by Hanna and others (1975), for the Los Angeles sheet of the Gravity Map of California.

Both the newer and older California Division of Mines and Geology gravity stations were referenced in the study to a local base station located on line G4, near Los Feliz Boulevard, which in turn was referenced to base station MW2 located at the California Institute of Technology (station WU4, Woollard and Rose, 1963, p. 122). The data of Corbato were referenced by him to a number of bases, in and near the study region, one of which is located at the Burbank airport (WA200,Woollard and Rose, 1963, p. 94). Most of the data on lines GV7 and GV8 were located for the present study at precise elevation markers previously established by the City of Los Angeles. Elevations for the other California Division of Mines and Geology gravity lines were obtained by surveying points along lines with a station interval of 400 feet.

The gravity data were reduced by means of a combined terrain correction and gravity reduction program by Plouff (1977) to complete Bouguer anomalies, using a density of 2.67 g/cm^3. Terrain corrections were made out to 166.7 km (100 miles) for all stations, using Hayford-Bowie charts to estimate corrections for the inner zones out through zone F, except for zone B, which was estimated in the field. Tabulated values of the principal facts for the earlier California Division of Mines and Geology stations were included in a report by Hill and others (1977). Tabulated values for the remaineder of these data are included in this report (pages 15-19).

Plate 2a shows all of the gravity data in the Verdugo-Eagle Rock-San Rafael fault zone region contoured at an interval of one milligal. [The area shown in the southeastern part of Plate 2a partly overlaps the area shown on Plate 2g of the report on the Santa Monica-Raymond fault zone (Hill and others, 1979b).]

INTERPRETATION OF DATA

Plate 2a shows that the central and eastern San Fernando Valley area is characterized by a prominent negative gravity anomaly. To the northeast of the valley area, the Verdugo Mountains and San Rafael Hills are marked by a northwest-trending positive anomaly; to the south of the valley, the Santa Monica Mountains are also represented by an east-trending high. Near Eagle Rock, the Verdugo Mountains-San Rafael Hills positive trend appears to merge with the eastern extension of the Santa Monica Mountains positive anomaly (as shown in broad outline by Hanna and others, 1975). The Verdugo-Eagle Rock fault zone is expressed by the gravity gradient between the San Fernando Valley low and the Verdugo Mountains-San Rafael Hills high.

The accumulated evidence depicted by gravity lines GV3-GV3S, G4-G4X, GV4, GV7 and GV8 (figures 2G-4G, 7G, and 8G, respectively)discloses a zone of relatively steep gravity gradients, downward to the southwest, along the southwestern edge of the Verdugo Mountains. The total gravity change along this zone of steep gradients is from 2 to 6 milligals. This zone probably represent a contrast in the subsurface separating relatively dense rocks on the northeast (possibly granitic and metamorphic rocks) and less dense rocks on the southwest (possibly Tertiary and younger sedimentary rocks and sediments) - possibly the Verdugo fault zone. The steepest gradients along the zone, as shown on the profiles, are centered near stations 14-16 on GV3-GV3S, stations 2-4 on G4X, station 4 on GV4, stations 13-14 on GV7, and stations 33-34 on GV8. From line GV4 southeastward to line GV3, the zone of steep gradients is located very close to the mountain front where the topographic slope increases sharply toward the northeast.

Because there are no gravity stations between lines GV3, west of Verdugo Canyon, and lines GV1 and GV2, east of Verdugo Canyon, the gravity contours on Plate 2a in this area are somewhat uncertain. Just east of this gap, on line GV2 (figure 1G), the segment of southward-decreasing gravity gradient centered near station 24 may represent the Eagle Rock fault. If this fault is continuous with the Verdugo fault to the northwest, there is evidently a northward bend in the fault in the vicinity of Verdugo Canyon. Alternatively, the Eagle Rock and Verdugo faults may be offset by another fault in this area.

East of lines GV1 and GV2, near Glendale, evidence in the gravity data for the Eagle Rock fault is not as clear as the evidence for the Verdugo fault to the northwest, except possibly on line G3 (Chapman and Chase, 1979, figures 3G and 15G). Line GV5 (figure 5G), east of Eagle Rock, shows no obvious anomalies, and line G7N (Chapman and Chase, 1979) may not extend sufficiently far northward to cross the fault.

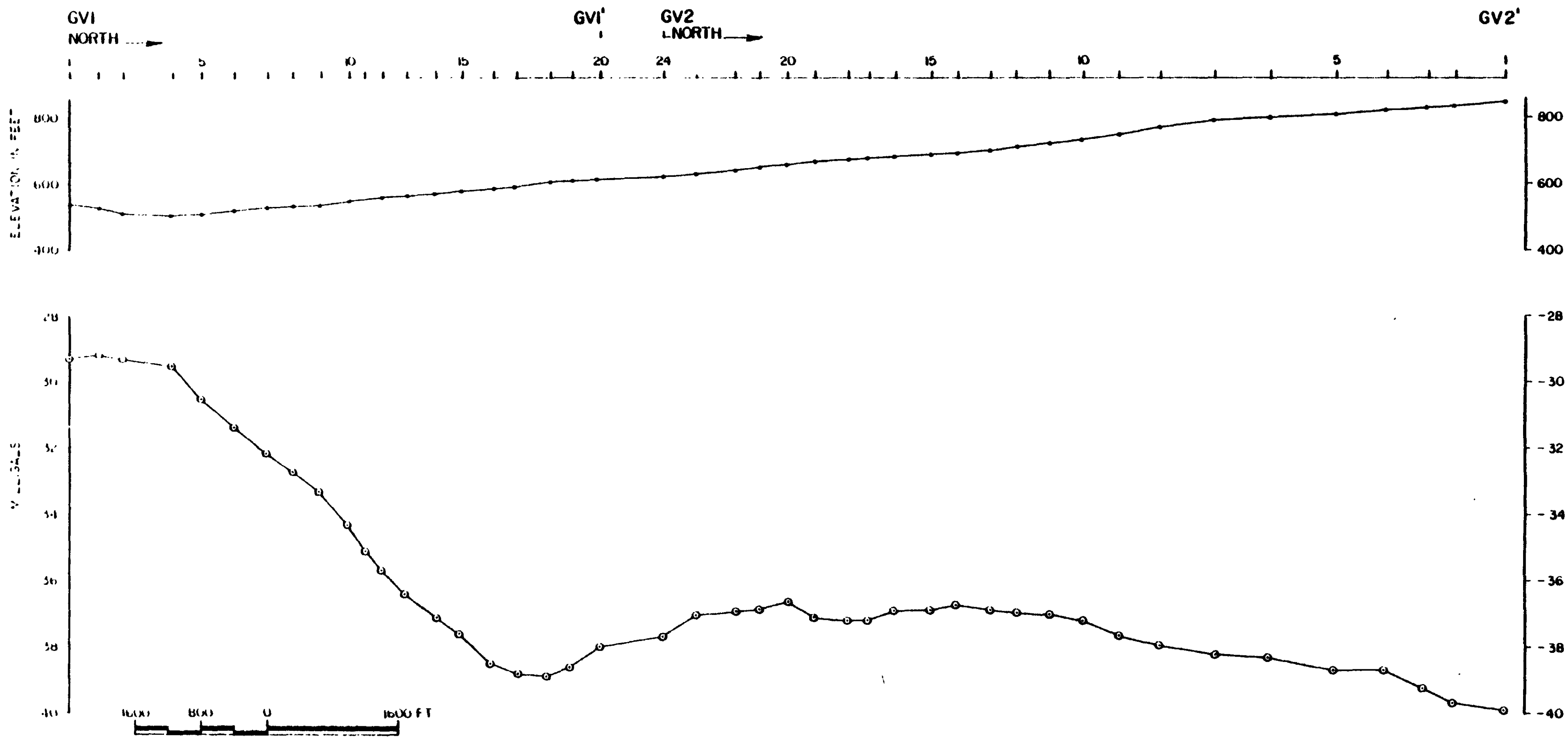
The northern ends of lines G1 and G2 (Plate 2a; Chapman and Chase, 1979, figure 1G) may show evidence for the possible southeastern extension of the San Rafael fault, however. The south-sloping gravity gradients centered near station 55 on line G1 and station 100 on line G2 may represent a contact in the subsurface between relatively dense rocks on the northeast and less dense rocks on the southwest.

The positive gravity anomaly that is present near the center of line G4 (Chapman and Chase, 1979, figure 2G) and on lines farther to the southeast (plate 2a) represents a basement high which is the eastern extension of the Santa Monica Mountains across the Los Angeles River. The south flank of this anomaly is the expression of the Hollywood fault zone, which was discussed in the earlier report by Chapman and Chase, (1979). The north flank of the anomaly may also represent one or more faults. For example, the northeast-trending gravity contours on the north side of the positive anomaly near Glendale could indicate a fault with a similar trend located just northwest of Forest Lawn Memorial Park and Adams Hill.

AEROMAGNETIC DATA

The U.S. Geological Survey aeromagnetic maps in this part of the Los Angeles region were flown at a flight elevation of 500 feet with a line spacing of about 1 mile (Andreason and others, 1964a,b). These maps disclose that a prominent positive magnetic anomaly is associated with at least the southern and eastern parts of the Verdugo Mountains-San Rafael Hills structural high. This anomaly extends southeastward into Pasadena and is bounded on the south and southwest by a relatively steep magnetic gradient. In general, this gradient follows the trend of the Verdugo, Eagle Rock, and San Rafael fault zones, and it may represent the boundary between the pre-late Cretaceous metamorphic and granitic rocks exposed in the Verdugo Mountains and San Rafael Hills, on the north, and the sedimentary rocks on the south.

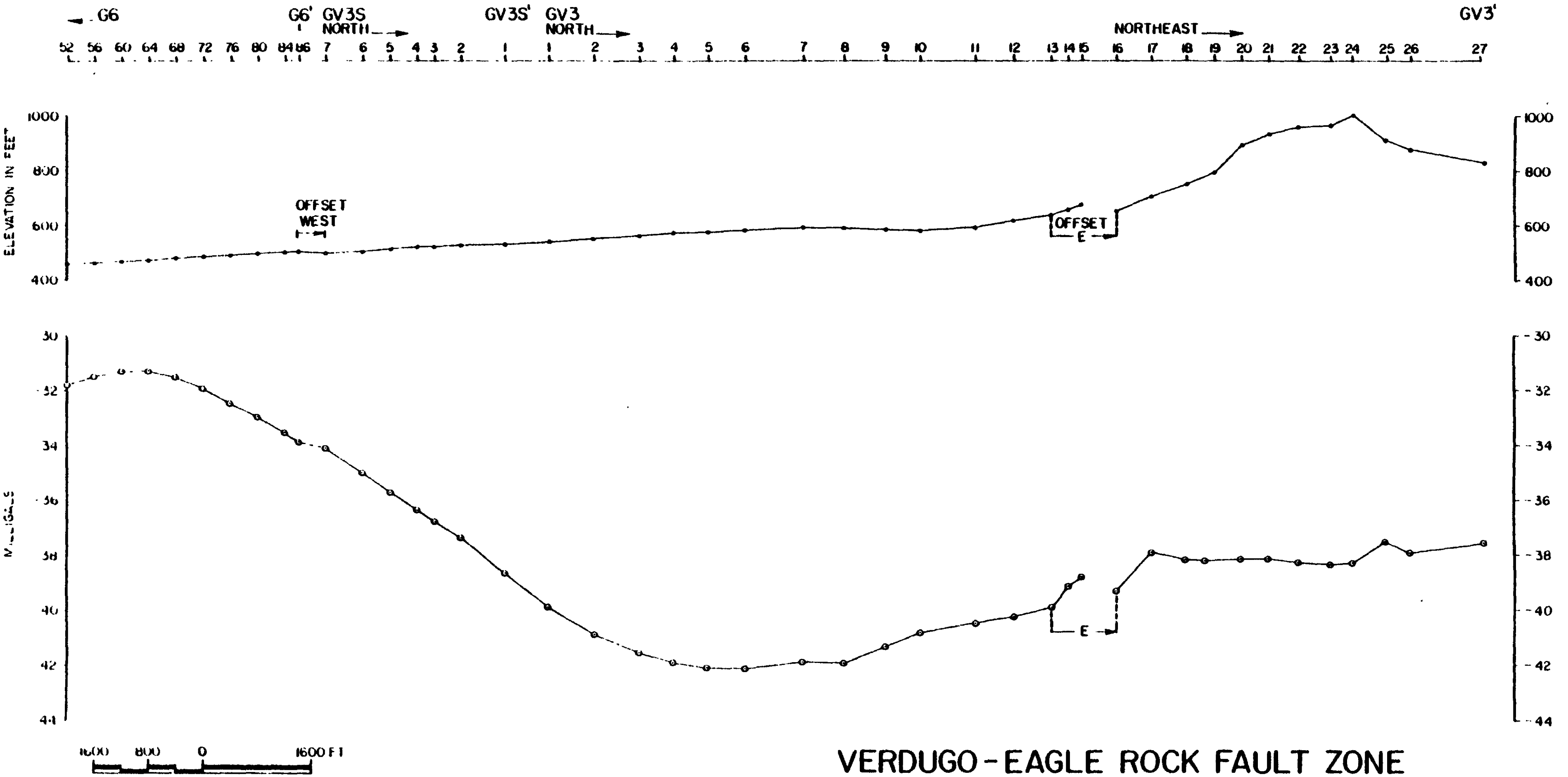
BOUGUER GRAVITY AND ELEVATION PROFILE GV1-GV1', GV2-GV2'



VERDUGO-EAGLE ROCK FAULT ZONE
LOS ANGELES COUNTY, CALIFORNIA
CALIFORNIA DIVISION OF MINES AND GEOLOGY
1979
REDUCTION DENSITY - 2.67 g/cm^3

FIG. 1G

BOUGUER GRAVITY AND ELEVATION PROFILE GV3S-GV3S', GV3-GV3'



VERDUGO - EAGLE ROCK FAULT ZONE
LOS ANGELES COUNTY, CALIFORNIA

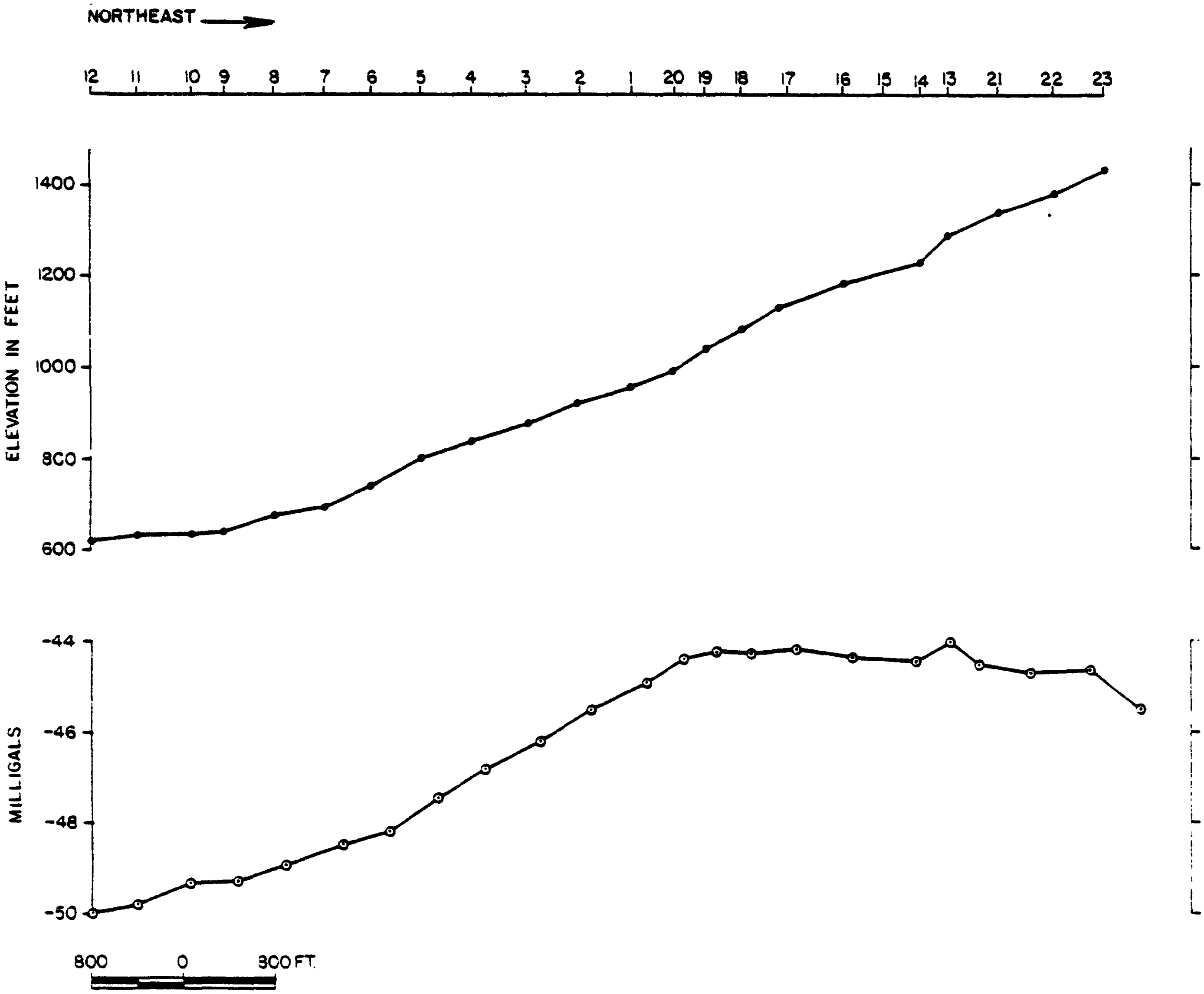
CALIFORNIA DIVISION OF MINES AND GEOLOGY

1979

REDUCTION DENSITY - 2.67 g/cm^3

FIG.2G

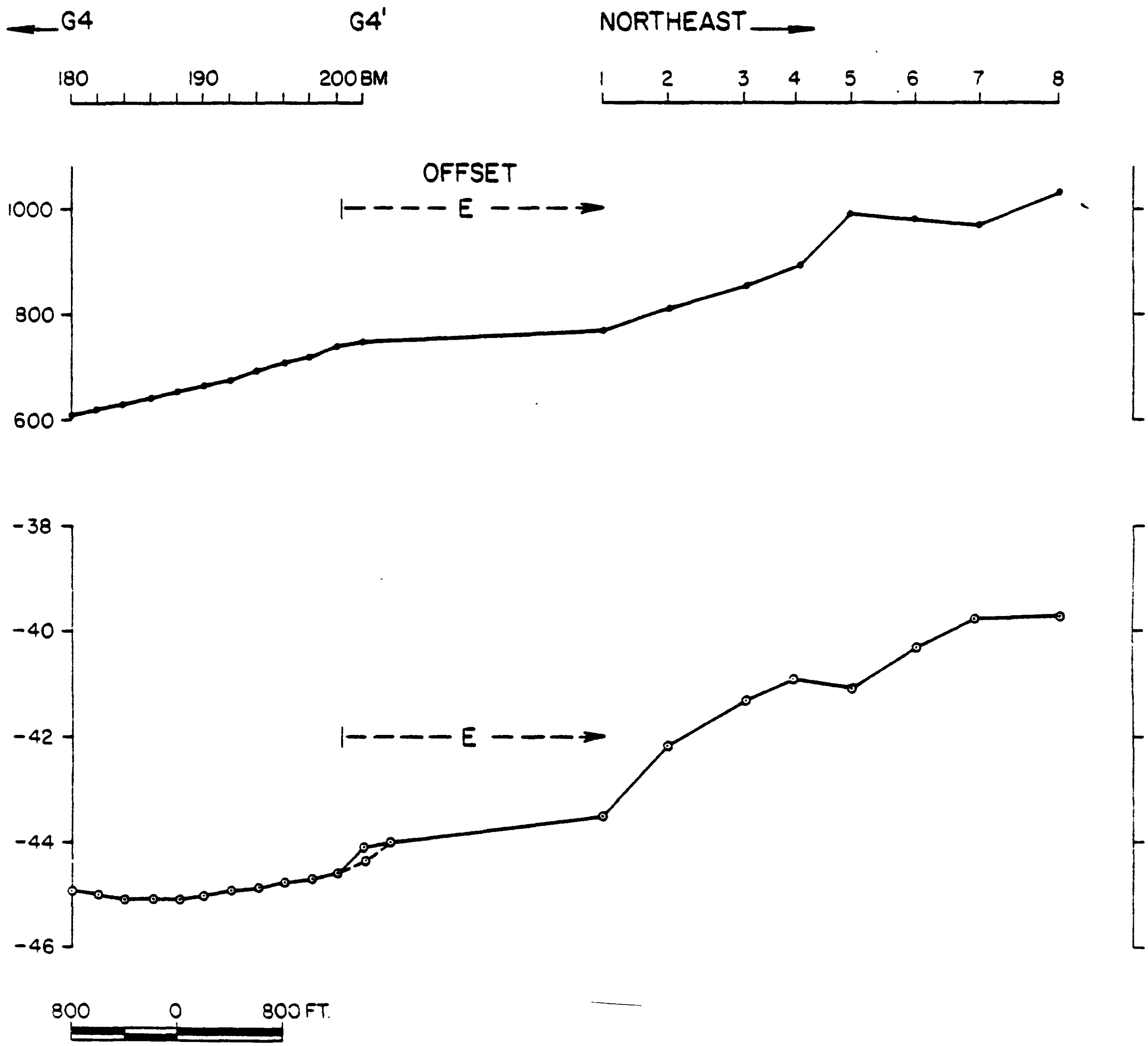
BOUGUER GRAVITY AND ELEVATION PROFILE GV4-GV4'



VERDUGO-EAGLE ROCK FAULT ZONE
LOS ANGELES COUNTY, CALIFORNIA
CALIFORNIA DIVISION OF MINES AND GEOLOGY
1979
REDUCTION DENSITY - 2.67 g/cm^3

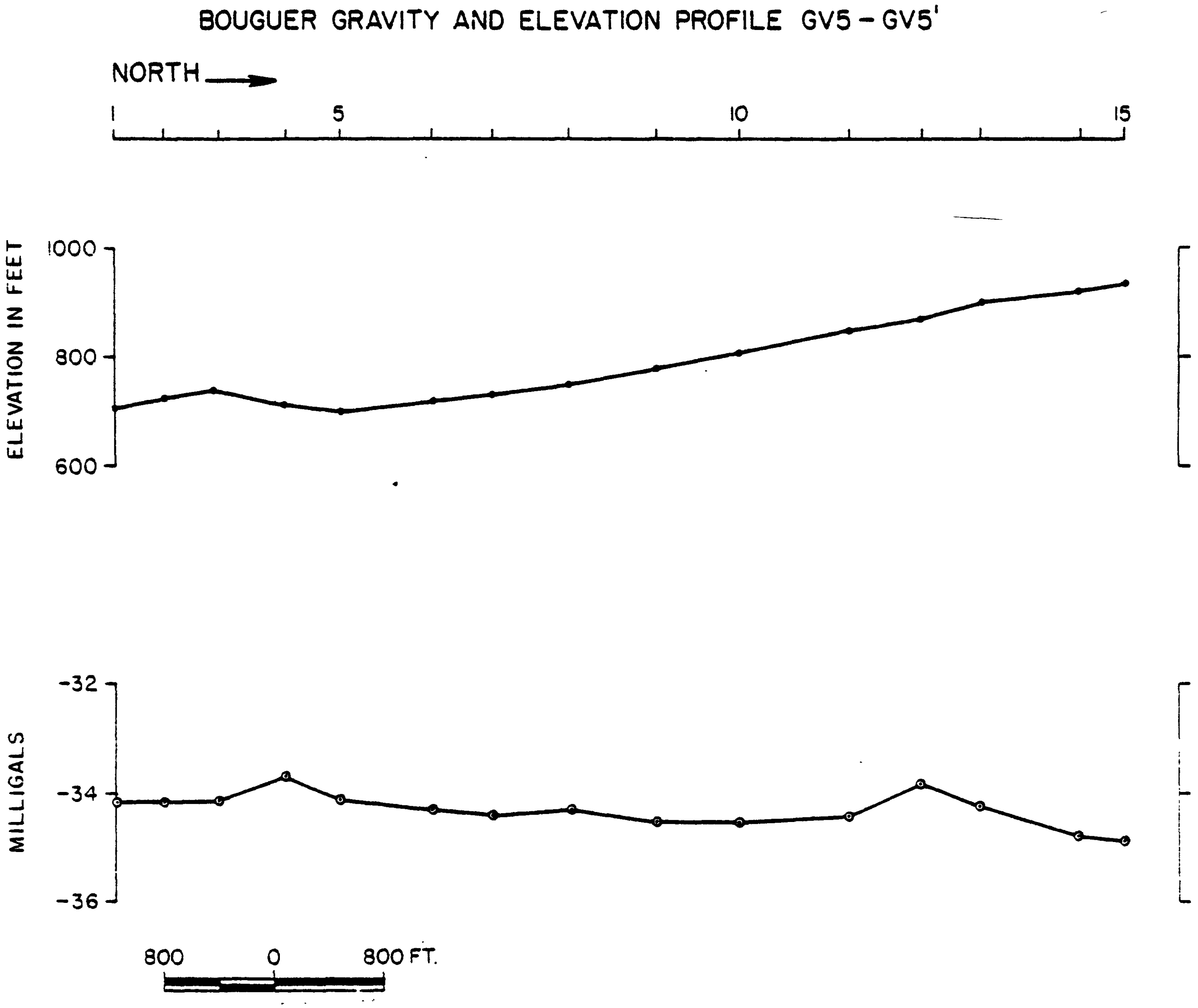
FIG. 3G

BOUGUER GRAVITY AND ELEVATION PROFILE G4X – G4X'



VERDUGO-EAGLE ROCK FAULT ZONE
LOS ANGELES COUNTY, CALIFORNIA
CALIFORNIA DIVISION OF MINES AND GEOLOGY
1979
REDUCTION DENSITY – 2.67 g/cm^3

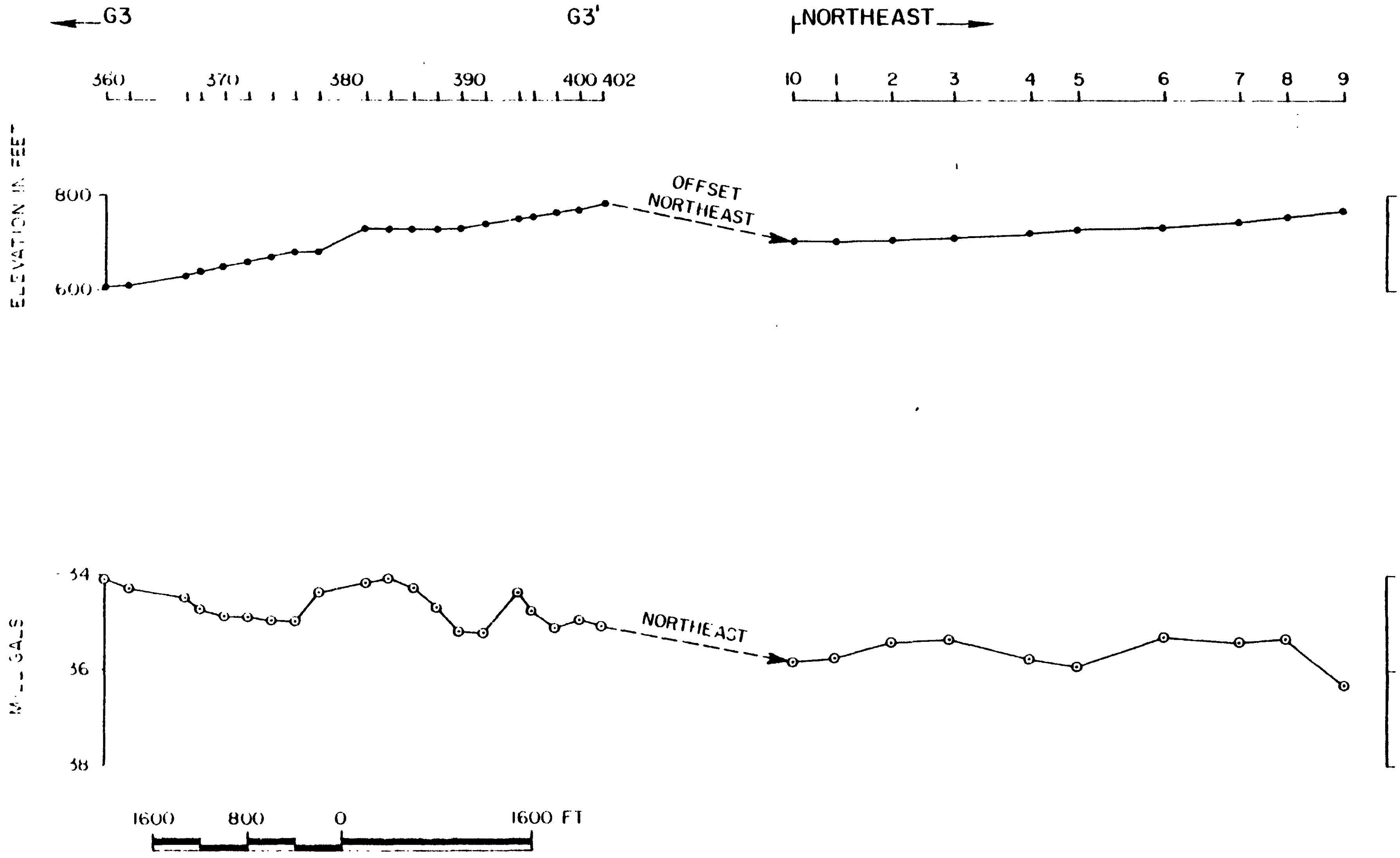
FIG. 4G



VERDUGO-EAGLE ROCK FAULT ZONE
LOS ANGELES COUNTY, CALIFORNIA
CALIFORNIA DIVISION OF MINES AND GEOLOGY
1979
REDUCTION DENSITY - 2.67 g/cm^3

FIG. 5G

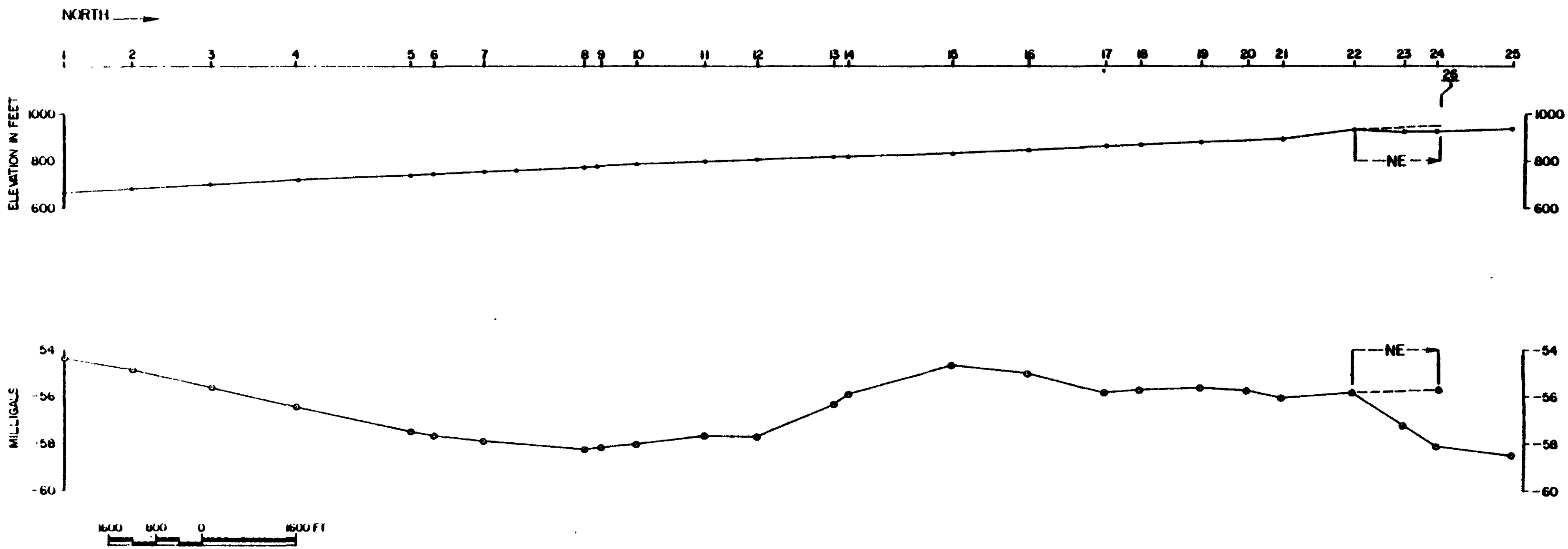
BOUGUER GRAVITY AND ELEVATION PROFILE GV6-GV6'



VERDUGO-EAGLE ROCK FAULT ZONE
LOS ANGELES COUNTY, CALIFORNIA
CALIFORNIA DIVISION OF MINES AND GEOLOGY
1979
REDUCTION DENSITY 2.67 g/cm³

FIG 6G

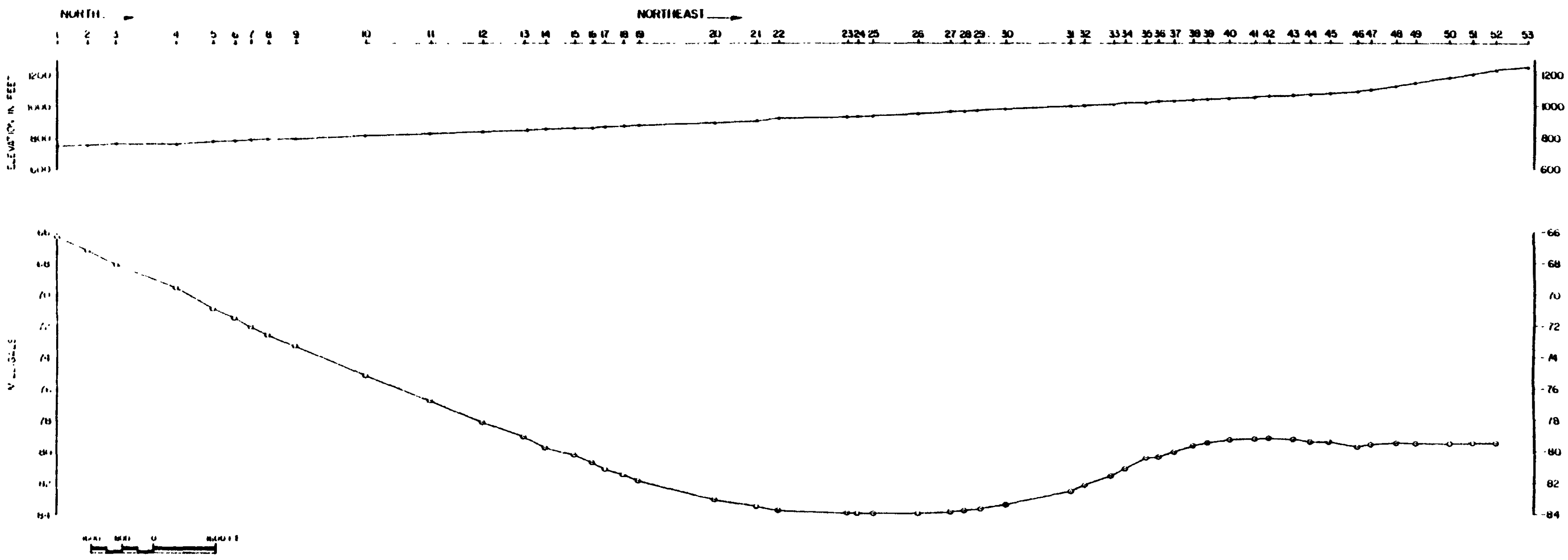
BOUGUER GRAVITY AND ELEVATION PROFILE GV7-GV7'



VERDUGO-EAGLE ROCK FAULT ZONE
LOS ANGELES COUNTY, CALIFORNIA
CALIFORNIA DIVISION OF MINES AND GEOLOGY
1979
REDUCTION DENSITY - 2.67 g/cm³

FIG. 7G

BOUGUER GRAVITY AND ELEVATION PROFILE GV8 - GV8'



VERDUGO-EAGLE ROCK FAULT ZONE
LOS ANGELES COUNTY, CALIFORNIA
CALIFORNIA DIVISION OF MINES AND GEOLOGY
1979
REDUCTION DENSITY - 2.67 g/cm³

FIG 8G

TABLE I

SUMMARY FOR 128 STATIONS IN LOS ANGELES AMS
COMPUTER TERRAIN CORRECTIONS CARRIED FROM CIRCULAR INNER RADIUS OF 2.290
TO 166.700 KILOMETERS. DENSITIES ARE 2.67 AND 2.30 DENSITY OF 2.67 IS USED FOR
VALUES IN COLUMNS LABELLED CC, TC, TER, (NEAR), AND TOT. TC-HAND CORRECTION
TER-TOTAL COMPUTER CORRECTION. (NEAR)-PART OF TOTAL THAT REPRESENTS CONTRIBUTION
OF COMPARTMENTS THAT INTERSECT INNER CIRCULAR RADIUS. TOT-HAND PLUS COMPUTER TERRAIN.

STATION	LATITUDE	LONGITUDE	ELEV	OBS GRAV	F.A.	S.B.1	S.B.2	CC	TC	TER	(NEAR)	TOT	C.B.1	C.B.2	ACC	STA
LAXGV11	34 7.90	118 14.30	540.3	979609.55	-12.04	-30.47	-27.91	0.23	0.21	1.18	0.02	1.39	-29.31	-26.92		GV11
LAXGV12	34 7.95	118 14.31	528.5	979610.39	-12.38	-30.41	-27.91	0.23	0.25	1.20	0.02	1.45	-29.18	-26.85		GV12
LAXGV13	34 8.00	118 14.31	514.0	979611.26	-12.94	-30.47	-28.05	0.22	0.19	1.23	0.02	1.42	-29.28	-27.02		GV13
LAXGV14	34 8.06	118 14.31	506.8	979611.55	-13.41	-30.70	-28.30	0.22	0.20	1.25	0.02	1.45	-29.47	-27.24		GV14
LAXGV15	34 8.15	118 14.32	512.4	979610.38	-14.18	-31.66	-29.24	0.22	0.12	1.27	0.02	1.39	-30.49	-28.23		GV15
LAXGV16	34 8.23	118 14.32	518.8	979609.25	-14.82	-32.52	-30.07	0.22	0.06	1.29	0.02	1.35	-31.39	-29.09		GV16
LAXGV17	34 8.28	118 14.32	524.6	979608.31	-15.29	-33.18	-30.70	0.23	0.03	1.30	0.02	1.33	-32.07	-29.74		GV17
LAXGV18	34 8.34	118 14.32	530.6	979607.38	-15.74	-33.83	-31.33	0.23	0.04	1.32	0.02	1.36	-32.70	-30.35		GV18
LAXGV19	34 8.39	118 14.32	536.1	979606.55	-16.12	-34.40	-31.87	0.23	0.03	1.33	0.02	1.36	-33.27	-30.90		GV19
LAXGV110	34 8.48	118 14.32	546.2	979605.02	-16.83	-35.45	-32.87	0.23	0.02	1.35	0.03	1.37	-34.32	-31.89		GV110
LAXGV111	34 8.55	118 14.32	554.3	979603.79	-17.39	-36.30	-33.68	0.24	0.01	1.37	0.03	1.38	-35.15	-32.69		GV111
LAXGV112	34 8.62	118 14.33	560.2	979602.90	-17.82	-36.93	-34.28	0.24	0.02	1.39	0.03	1.41	-35.76	-33.27		GV112
LAXGV113	34 8.67	118 14.32	566.1	979601.94	-18.30	-37.61	-34.93	0.24	0.03	1.40	0.03	1.43	-36.41	-33.90		GV113
LAXGV114	34 8.73	118 14.33	574.1	979600.88	-18.69	-38.27	-35.56	0.25	0.03	1.42	0.03	1.45	-37.07	-34.52		GV114
LAXGV115	34 8.77	118 14.33	580.1	979599.99	-19.07	-38.86	-36.11	0.25	0.03	1.43	0.04	1.46	-37.65	-35.07		GV115
LAXGV116	34 8.80	118 14.31	591.0	979598.55	-19.53	-39.68	-36.89	0.25	0.04	1.43	0.05	1.47	-38.47	-35.84		GV116
LAXGV117	34 8.94	118 14.29	597.2	979597.97	-19.72	-40.09	-37.26	0.25	0.05	1.48	0.07	1.53	-38.81	-36.16		GV117
LAXGV118	34 8.99	118 14.27	604.2	979597.52	-19.58	-40.19	-37.33	0.26	0.07	1.51	0.07	1.58	-38.86	-36.19		GV118
LAXGV119	34 9.04	118 14.22	610.3	979597.47	-19.13	-39.94	-37.06	0.26	0.07	1.54	0.07	1.61	-38.60	-35.90		GV119
LAXGV120	34 9.06	118 14.15	616.2	979597.68	-18.39	-39.41	-36.49	0.26	0.10	1.55	0.06	1.65	-38.02	-35.30		GV120
LAXGV224	34 9.13	118 14.17	618.0	979597.80	-18.20	-39.28	-36.36	0.26	0.20	1.57	0.06	1.77	-37.77	-35.06		GV224
LAXGV223	34 9.19	118 14.18	629.7	979597.77	-17.21	-38.69	-35.71	0.27	0.21	1.59	0.06	1.80	-37.16	-34.39		GV223
LAXGV222	34 9.24	118 14.20	642.3	979597.30	-16.57	-38.47	-35.44	0.27	0.18	1.59	0.06	1.77	-36.97	-34.14		GV222
LAXGV221	34 9.30	118 14.20	650.8	979596.84	-16.31	-38.51	-35.43	0.28	0.25	1.61	0.09	1.86	-36.92	-34.06		GV221
LAXGV220	34 9.36	118 14.20	654.9	979596.78	-16.07	-38.40	-35.31	0.28	0.37	1.64	0.09	2.01	-36.67	-33.32		GV220
LAXGV219	34 9.41	118 14.19	663.6	979595.98	-16.12	-38.75	-35.62	0.28	0.24	1.65	0.09	1.89	-37.14	-34.23		GV219
LAXGV218	34 9.46	118 14.18	673.3	979595.34	-15.92	-38.88	-35.70	0.29	0.28	1.67	0.09	1.95	-37.22	-34.27		GV218
LAXGV217	34 9.52	118 14.17	676.4	979595.22	-15.83	-38.90	-35.70	0.29	0.26	1.70	0.09	1.95	-37.23	-34.26		GV217
LAXGV216	34 9.59	118 14.15	679.6	979595.17	-15.68	-38.86	-35.64	0.29	0.52	1.73	0.09	2.25	-36.89	-33.95		GV216
LAXGV215	34 9.65	118 14.14	688.1	979594.71	-15.42	-38.89	-35.64	0.29	0.50	1.75	0.09	2.25	-36.93	-33.95		GV215
LAXGV214	34 9.70	118 14.10	693.6	979594.41	-15.27	-38.93	-35.65	0.29	0.71	1.78	0.08	2.49	-36.73	-33.76		GV214
LAXGV213	34 9.75	118 14.04	701.9	979593.69	-15.28	-39.22	-35.90	0.30	0.88	1.80	0.08	2.68	-36.84	-33.85		GV213
LAXGV212	34 9.80	118 13.98	708.8	979593.40	-14.99	-39.17	-35.82	0.30	0.77	1.83	0.13	2.60	-36.87	-33.84		GV212
LAXGV211	34 9.84	118 13.93	718.6	979592.73	-14.80	-39.31	-35.91	0.30	0.75	1.84	0.13	2.59	-37.02	-33.94		GV211
LAXGV210	34 9.90	118 13.87	731.4	979591.74	-14.67	-39.61	-36.16	0.31	0.84	1.86	0.13	2.70	-37.22	-34.10		GV210
LAXGV29	34 10.00	118 13.78	753.4	979590.27	-14.21	-39.90	-36.34	0.32	0.70	1.89	0.15	2.59	-37.63	-34.39		GV29
LAXGV28	34 10.05	118 13.73	772.0	979589.09	-13.71	-40.04	-36.39	0.32	0.52	1.89	0.14	2.41	-37.95	-34.59		GV28
LAXGV27	34 10.22	118 13.70	792.6	979587.82	-13.28	-40.31	-36.56	0.33	0.51	1.96	0.13	2.47	-38.17	-34.72		GV27
LAXGV26	34 10.32	118 13.69	795.9	979587.42	-13.51	-40.65	-36.89	0.33	0.69	2.01	0.13	2.70	-38.28	-34.85		GV26
LAXGV25	34 10.40	118 13.69	805.1	979586.58	-13.59	-41.05	-37.25	0.34	0.60	2.05	0.13	2.65	-38.74	-35.26		GV25
LAXGV24	34 10.46	118 13.69	819.1	979585.74	-13.20	-41.14	-37.27	0.34	0.70	2.06	0.20	2.76	-38.72	-35.18		GV24
LAXGV23	34 10.53	118 13.69	827.3	979584.89	-13.39	-41.60	-37.69	0.35	0.67	2.09	0.20	2.76	-39.19	-35.61		GV23
LAXGV22	34 10.57	118 13.69	836.9	979584.12	-13.30	-41.84	-37.89	0.35	0.36	2.09	0.20	2.45	-39.74	-36.07		GV22
LAXGV21	34 10.63	118 13.70	846.1	979583.38	-13.26	-42.11	-38.11	0.35	0.49	2.11	0.19	2.60	-39.96	-36.18		GV21
LAXGV31	34 8.73	118 15.10	543.3	979600.01	-22.53	-41.06	-38.49	0.23	0.01	1.39	0.05	1.40	-39.89	-37.48		GV31
LAXGV32	34 8.88	118 15.10	555.1	979598.42	-23.15	-42.08	-39.45	0.24	0.01	1.42	0.05	1.43	-40.89	-38.43		GV32
LAXGV33	34 8.94	118 15.10	564.5	979597.33	-23.51	-42.76	-40.09	0.24	0.01	1.45	0.05	1.46	-41.54	-39.04		GV33

LAXGV34	34	9.10	118	15.10	573.3	979596.52	-23.64	-43.19	-40.48	0.25	0.02	1.51	0.05	1.53	-41.91	-39.38	GV34
LAXGV35	34	9.18	118	15.10	577.9	979596.17	-23.67	-43.38	-40.65	0.25	0.02	1.54	0.06	1.56	-42.07	-39.52	GV35
LAXGV36	34	9.27	118	15.10	583.2	979595.85	-23.62	-43.51	-40.75	0.25	0.05	1.57	0.06	1.62	-42.13	-39.57	GV36
LAXGV37	34	9.41	118	15.10	593.0	979595.33	-23.41	-43.64	-40.83	0.25	0.41	1.63	0.06	2.04	-41.85	-39.29	GV37
LAXGV38	34	9.51	118	15.10	594.8	979595.53	-23.18	-43.47	-40.66	0.25	0.14	1.68	0.06	1.82	-41.90	-39.30	GV38
LAXGV39	34	9.61	118	15.10	590.3	979596.42	-22.85	-42.99	-40.20	0.25	0.17	1.75	0.06	1.92	-41.32	-38.76	GV39
LAXGV310	34	9.69	118	15.10	587.4	979597.09	-22.55	-42.59	-39.81	0.25	0.24	1.80	0.05	2.04	-40.80	-38.27	GV310
LAXGV311	34	9.82	118	15.10	596.9	979596.84	-22.11	-42.46	-39.64	0.25	0.41	1.88	0.23	2.29	-40.43	-37.89	GV311
LAXGV312	34	9.91	118	15.10	620.7	979595.39	-21.44	-42.61	-39.68	0.26	0.76	1.90	0.23	2.66	-40.22	-37.62	GV312
LAXGV313	34	10.00	118	15.11	638.7	979594.63	-20.64	-42.42	-39.40	0.27	0.87	1.93	0.23	2.80	-39.99	-37.23	GV313
LAXGV314	34	10.04	118	15.11	656.6	979593.95	-19.69	-42.08	-38.98	0.28	1.32	1.93	0.26	3.25	-39.11	-36.42	GV314
LAXGV315	34	10.07	118	15.12	674.3	979592.83	-18.71	-41.88	-38.67	0.29	1.47	1.91	0.26	3.38	-38.79	-36.01	GV315
LAXGV316	34	10.00	118	15.04	649.9	979594.33	-19.88	-42.05	-38.98	0.28	1.11	1.92	0.23	3.03	-39.30	-36.61	GV316
LAXGV317	34	10.08	118	15.04	711.8	979591.53	-16.97	-41.25	-37.88	0.30	1.79	1.88	0.24	3.67	-37.88	-34.99	GV317
LAXGV318	34	10.16	118	14.98	751.8	979588.90	-15.95	-41.59	-38.04	0.32	1.89	1.88	0.24	3.77	-38.14	-35.07	GV318
LAXGV319	34	10.21	118	14.94	793.6	979586.45	-14.54	-41.61	-37.86	0.33	1.89	1.86	0.23	3.75	-38.19	-34.92	GV319
LAXGV320	34	10.24	118	14.38	891.5	979580.91	-10.91	-41.32	-37.10	0.37	1.78	1.79	0.19	3.57	-38.12	-34.35	GV320
LAXGV321	34	10.22	118	14.80	932.2	979573.76	-9.21	-41.00	-36.59	0.39	1.52	1.76	0.18	3.28	-38.11	-34.11	GV321
LAXGV322	34	10.17	118	14.74	960.6	979576.87	-8.35	-41.12	-36.58	0.40	1.54	1.73	0.18	3.27	-38.25	-34.11	GV322
LAXGV323	34	10.14	118	14.66	965.2	979576.42	-8.33	-41.25	-36.69	0.40	1.60	1.72	0.17	3.32	-38.33	-34.17	GV323
LAXGV324	34	10.16	118	14.60	1003.7	979574.40	-6.76	-40.99	-36.25	0.41	1.42	1.72	0.18	3.14	-38.27	-33.90	GV324
LAXGV325	34	10.19	118	14.50	913.0	979580.75	-8.98	-40.12	-35.80	0.38	1.20	1.78	0.15	2.98	-37.52	-33.57	GV325
LAXGV326	34	10.23	118	14.46	874.6	979582.93	-10.47	-40.30	-36.16	0.37	0.93	1.83	0.18	2.76	-37.90	-34.10	GV326
LAXGV327	34	10.34	118	14.29	830.5	979587.64	-10.06	-38.39	-34.46	0.35	1.22	1.94	0.20	3.16	-35.57	-32.04	GV327
LAXGV412	34	11.28	118	19.05	611.2	979588.64	-31.00	-51.84	-48.96	0.26	0.16	1.83	0.17	1.99	-50.12	-47.47	GV412
LAXGV411	34	11.35	118	18.98	635.0	979587.52	-29.98	-51.64	-48.63	0.27	0.16	1.86	0.16	2.02	-49.88	-47.12	GV411
LAXGV410	34	11.42	118	18.90	656.9	979586.55	-28.99	-51.39	-48.29	0.28	0.25	1.91	0.16	2.16	-49.51	-46.66	GV410
LAXGV49	34	11.37	118	18.84	658.8	979586.38	-28.91	-51.38	-48.26	0.28	0.22	1.90	0.16	2.12	-49.54	-46.68	GV49
LAXGV48	34	11.45	118	18.77	690.4	979584.86	-27.57	-51.11	-47.85	0.29	0.34	1.93	0.16	2.27	-49.13	-46.14	GV48
LAXGV47	34	11.52	118	18.70	724.5	979583.33	-25.99	-50.70	-47.27	0.31	0.37	1.96	0.15	2.33	-48.68	-45.53	GV47
LAXGV46	34	11.59	118	18.64	759.4	979581.72	-24.41	-50.31	-46.72	0.32	0.45	1.98	0.13	2.43	-48.20	-44.91	GV46
LAXGV45	34	11.66	118	18.55	802.0	979579.77	-22.45	-49.81	-46.02	0.34	0.64	2.00	0.12	2.64	-47.50	-44.03	GV45
LAXGV44	34	11.73	118	18.48	841.9	979577.93	-20.64	-49.35	-45.37	0.35	0.78	2.02	0.13	2.80	-46.90	-43.26	GV44
LAXGV43	34	11.79	118	18.42	878.9	979576.27	-18.90	-48.88	-44.72	0.37	0.83	2.04	0.38	2.87	-46.38	-42.57	GV43
LAXGV42	34	11.86	118	18.34	915.1	979574.66	-17.20	-48.42	-44.09	0.38	1.19	2.06	0.53	3.25	-45.54	-41.61	GV42
LAXGV41	34	11.94	118	18.27	958.2	979572.64	-15.23	-47.96	-43.43	0.40	1.34	2.08	0.56	3.42	-44.94	-40.83	GV41
LAXGV420	34	11.99	118	18.23	986.7	979571.06	-14.25	-47.90	-43.24	0.41	1.74	2.08	0.56	3.82	-44.49	-40.30	GV420
LAXGV419	34	12.04	118	18.22	1037.1	979568.13	-12.51	-47.88	-42.98	0.43	1.94	2.06	0.54	4.00	-44.31	-39.90	GV419
LAXGV418	34	12.11	118	18.21	1079.5	979565.80	-10.95	-47.77	-42.67	0.44	1.82	2.05	0.51	3.87	-44.34	-39.71	GV418
LAXGV417	34	12.17	118	18.25	1123.9	979563.30	-9.36	-47.69	-42.38	0.46	1.91	2.03	0.49	3.94	-44.21	-39.38	GV417
LAXGV416	34	12.26	118	18.23	1180.4	979559.87	-7.60	-47.86	-42.28	0.48	1.93	2.01	0.43	3.94	-44.40	-39.30	GV416
LAXGV415	34	12.33	118	18.26	1202.9	979558.48	-6.97	-48.00	-42.31	0.49	2.03	2.02	0.42	4.05	-44.44	-39.24	GV415
LAXGV414	34	12.37	118	18.23	1238.2	979556.52	-5.67	-47.90	-42.05	0.50	2.32	2.02	0.47	4.34	-44.06	-38.74	GV414
LAXGV413	34	12.42	118	18.23	1286.7	979553.35	-4.34	-48.23	-42.15	0.52	2.31	2.01	0.45	4.32	-44.43	-38.87	GV413
LAXGV421	34	12.52	118	18.22	1332.6	979550.14	-3.39	-48.83	-42.53	0.54	2.60	2.02	0.43	4.62	-44.75	-39.01	GV421
LAXGV422	34	12.61	118	18.22	1377.9	979547.13	-2.25	-49.25	-42.74	0.55	3.16	2.01	0.41	5.17	-44.63	-38.75	GV422
LAXGV423	34	12.70	118	18.26	1432.0	979543.32	-1.10	-49.94	-43.17	0.57	3.05	2.01	0.38	5.06	-45.45	-39.31	GV423
LAXG4XBM	34	10.52	118	16.20	730.8	979584.93	-22.40	-47.32	-43.87	0.31	1.50	1.99	0.25	3.49	-44.14	-41.13	G4XBM
LAXG4X1	34	10.47	118	16.09	742.1	979584.93	-21.27	-46.58	-43.07	0.31	1.47	1.96	0.25	3.43	-43.46	-40.39	G4X1
LAXG4X2	34	10.55	118	16.04	778.4	979583.75	-19.14	-45.69	-42.01	0.33	1.90	1.96	0.23	3.86	-42.16	-38.97	G4X2
LAXG4X3	34	10.63	118	15.98	813.6	979581.65	-18.04	-45.79	-41.95	0.34	2.93	1.96	0.20	4.89	-41.24	-38.03	G4X3
LAXG4X4	34	10.67	118	15.93	852.8	979579.53	-16.53	-45.62	-41.59	0.36	3.25	1.94	0.18	5.19	-40.79	-37.43	G4X4
LAXG4X5	34	10.65	118	15.95	987.9	979571.60	-11.73	-45.42	-40.75	0.41	3.16	1.82	0.19	4.98	-40.84	-36.81	G4X5
LAXG4X6	34	10.68	118	15.77	979.0	979572.36	-11.85	-45.24	-40.61	0.41	3.45	1.84	0.16	5.29	-40.35	-36.40	G4X6
LAXG4X7	34	10.72	118	15.68	965.0	979572.77	-12.81	-45.72	-41.16	0.40	4.49	1.86	0.14	6.35	-39.77	-36.03	G4X7
LAXG4X8	34	10.72	118	15.58	1037.2	979567.88	-10.91	-46.28	-41.38	0.43	5.14	1.83	0.14	6.97	-39.74	-35.75	G4X8
LAXGV51	34	7.80	118	11.23	711.4	979594.35	-11.01	-35.27	-31.91	0.30	0.19	1.31	0.05	1.50	-34.07	-30.88	GV51

LAXGV52	34	7.85	118	11.26	722.2	979593.73	-10.68	-35.31	-31.90	0.31	0.25	1.32	0.05	1.57	-34.05	-30.81	GV52
LAXGV53	34	7.92	118	11.29	738.3	979592.83	-10.16	-35.34	-31.86	0.31	0.25	1.33	0.05	1.58	-34.08	-30.76	GV53
LAXGV54	34	8.00	118	11.32	710.4	979594.52	-11.11	-35.34	-31.98	0.30	0.59	1.36	0.06	1.95	-33.69	-30.56	GV54
LAXGV55	34	8.06	118	11.30	700.6	979595.08	-11.66	-35.55	-32.24	0.30	0.35	1.38	0.06	1.73	-34.11	-31.00	GV55
LAXGV56	34	8.16	118	11.25	718.7	979593.97	-11.20	-35.71	-32.32	0.30	0.25	1.41	0.06	1.66	-34.36	-31.15	GV56
LAXGV57	34	8.23	118	11.23	730.3	979593.30	-10.98	-35.79	-32.34	0.31	0.27	1.42	0.06	1.69	-34.40	-31.14	GV57
LAXGV58	34	8.31	118	11.19	747.9	979592.26	-10.37	-35.88	-32.35	0.32	0.41	1.44	0.05	1.85	-34.35	-31.02	GV58
LAXGV59	34	8.41	118	11.16	781.7	979590.12	-9.49	-36.14	-32.44	0.33	0.48	1.45	0.04	1.93	-34.53	-31.06	GV59
LAXGV510	34	8.50	118	11.13	812.4	979588.30	-8.53	-36.24	-32.40	0.34	0.55	1.47	0.04	2.02	-34.57	-30.96	GV510
LAXGV511	34	8.62	118	11.04	854.5	979585.84	-7.20	-36.35	-32.31	0.36	0.78	1.49	0.03	2.27	-34.43	-30.66	GV511
LAXGV512	34	8.68	118	10.97	872.6	979584.56	-6.86	-36.62	-32.50	0.36	1.67	1.51	0.03	3.18	-33.81	-30.08	GV512
LAXGV513	34	8.75	118	11.02	899.2	979583.11	-5.91	-36.58	-32.33	0.37	1.23	1.51	0.02	2.74	-34.21	-30.29	GV513
LAXGV514	34	8.87	118	10.99	922.1	979581.22	-5.81	-37.26	-32.90	0.38	1.30	1.54	0.04	2.84	-34.81	-30.79	GV514
LAXGV515	34	8.93	118	10.99	931.4	979580.47	-5.77	-37.54	-33.13	0.39	1.47	1.55	0.03	3.02	-34.90	-30.86	GV515
LAXGV610	34	9.36	118	13.33	701.8	979594.43	-14.01	-37.94	-34.63	0.30	0.78	1.69	0.11	2.47	-35.77	-32.75	GV610
LAXGV61	34	9.40	118	13.27	709.8	979593.95	-13.79	-38.00	-34.64	0.30	0.93	1.71	0.14	2.64	-35.66	-32.63	GV61
LAXGV62	34	9.44	118	13.19	710.9	979593.97	-13.72	-37.97	-34.61	0.30	1.21	1.73	0.14	2.94	-35.33	-32.33	GV62
LAXGV63	34	9.49	118	13.10	715.0	979593.47	-13.91	-38.29	-34.91	0.30	1.61	1.76	0.14	3.37	-35.22	-32.27	GV63
LAXGV64	34	9.56	118	13.01	722.8	979592.53	-14.21	-38.36	-35.45	0.31	1.72	1.80	0.14	3.52	-35.65	-32.63	GV64
LAXGV65	34	9.57	118	12.94	725.7	979592.06	-14.42	-39.17	-35.74	0.31	1.83	1.80	0.13	3.63	-35.85	-32.88	GV65
LAXGV66	34	9.58	118	12.80	738.5	979591.23	-14.06	-39.25	-35.76	0.31	2.53	1.80	0.13	4.33	-35.23	-32.30	GV66
LAXGV67	34	9.63	118	12.69	749.8	979590.39	-13.91	-39.48	-35.94	0.32	2.57	1.81	0.11	4.38	-35.41	-32.43	GV67
LAXGV68	34	9.67	118	12.64	757.2	979589.62	-14.04	-39.86	-36.29	0.32	3.00	1.82	0.10	4.82	-35.36	-32.41	GV68
LAXGV69	34	9.73	118	12.56	772.0	979588.51	-13.84	-40.17	-36.52	0.32	2.37	1.82	0.08	4.19	-36.30	-33.19	GV69

SUMMARY FOR 85 STATIONS IN LOS ANGELES AMS
COMPUTER TERRAIN CORRECTIONS CARRIED FROM CIRCULAR INNER RADIUS OF 2.290
TO 166.700 KILOMETERS. DENSITIES ARE 2.67 AND 2.30 DENSITY OF 2.67 IS USED FOR
VALUES IN COLUMNS LABELLED CC, TC, TER, (NEAR), AND TOT. TC-HAND CORRECTION
TER-TOTAL COMPUTER CORRECTION. (NEAR)-PART OF TOTAL THAT REPRESENTS CONTRIBUTION
OF COMPARTMENTS THAT INTERSECT INNER CIRCULAR RADIUS. TOT-HAND PLUS COMPUTER TERRAIN.

STATION	LATITUDE	LONGITUDE	ELEV	OBS GRAV	F.A.	S.B.1	S.B.2	CC	TC	TER	(NEAR)	TOT	C.B.1	C.B.2	ACC	STA
LAXGU7 1	34 11.11	118 22.18	668.2	979581.75	-32.29	-55.08	-51.92	0.28	0.0	0.98	0.00	0.98	-54.38	-51.32		GU7 1
LAXGU7 2	34 11.30	118 22.17	683.6	979580.58	-32.28	-55.59	-52.36	0.29	0.0	0.99	0.00	0.99	-54.89	-51.75		GU7 2
LAXGU7 3	34 11.53	118 22.18	700.1	979579.16	-32.47	-56.34	-53.04	0.30	0.0	1.02	0.00	1.02	-55.62	-52.41		GU7 3
LAXGU7 4	34 11.76	118 22.16	718.5	979577.54	-32.68	-57.18	-53.79	0.30	0.0	1.05	0.00	1.05	-56.43	-53.14		GU7 4
LAXGU7 5	34 12.06	118 22.18	736.9	979575.80	-33.13	-58.26	-54.78	0.31	0.0	1.08	0.01	1.08	-57.49	-54.12		GU7 5
LAXGU7 6	34 12.15	118 22.17	741.9	979575.45	-33.11	-58.41	-54.91	0.31	0.0	1.09	0.01	1.09	-57.64	-54.24		GU7 6
LAXGU7 7	34 12.28	118 22.18	753.4	979574.67	-32.99	-58.69	-55.13	0.32	0.0	1.11	0.02	1.11	-57.90	-54.45		GU7 7
LAXGU7 8	34 12.56	118 22.18	771.1	979573.59	-32.80	-59.10	-55.45	0.32	0.0	1.15	0.02	1.15	-58.27	-54.74		GU7 8
LAXGU7 9	34 12.63	118 22.18	775.5	979573.50	-32.57	-59.02	-55.35	0.33	0.0	1.16	0.02	1.16	-58.18	-54.64		GU7 9
LAXGU710	34 12.73	118 22.18	781.7	979573.41	-32.22	-58.88	-55.18	0.33	0.0	1.18	0.02	1.18	-58.03	-54.45		GU710
LAXGU711	34 12.92	118 22.17	795.1	979573.20	-31.43	-58.55	-54.79	0.33	0.0	1.20	0.03	1.20	-57.68	-54.05		GU711
LAXGU712	34 13.07	118 22.18	805.2	979572.69	-31.20	-58.66	-54.86	0.34	0.01	1.22	0.03	1.23	-57.77	-54.09		GU712
LAXGU713	34 13.23	118 22.05	814.0	979573.72	-29.57	-57.33	-53.48	0.34	0.03	1.27	0.04	1.30	-56.37	-52.65		GU713
LAXGU714	34 13.28	118 22.00	816.0	979574.12	-29.05	-56.88	-53.02	0.34	0.02	1.29	0.04	1.31	-55.91	-52.19		GU714
LAXGU715	34 13.53	118 21.88	829.7	979574.81	-27.42	-55.72	-51.80	0.35	0.05	1.36	0.04	1.41	-54.65	-50.88		GU715
LAXGU716	34 13.74	118 21.93	843.9	979573.88	-27.31	-56.09	-52.10	0.35	0.05	1.38	0.04	1.43	-55.01	-51.17		GU716
LAXGU717	34 13.95	118 21.95	860.1	979572.35	-27.61	-56.94	-52.88	0.36	0.07	1.40	0.04	1.47	-55.83	-51.92		GU717
LAXGU718	34 14.04	118 21.97	867.5	979572.16	-27.23	-56.61	-52.71	0.36	0.04	1.40	0.04	1.44	-55.73	-51.78		GU718
LAXGU719	34 14.21	118 22.02	880.5	979571.69	-26.71	-56.74	-52.58	0.37	0.08	1.41	0.04	1.49	-55.62	-51.61		GU719
LAXGU720	34 14.34	118 22.00	885.5	979571.33	-26.76	-56.98	-52.80	0.37	0.15	1.44	0.04	1.59	-55.77	-51.75		GU720
LAXGU721	34 14.43	118 22.01	892.7	979570.64	-26.92	-57.37	-53.15	0.37	0.24	1.45	0.04	1.69	-56.05	-52.01		GU721
LAXGU722	34 14.62	118 21.91	935.9	979568.38	-25.38	-57.30	-52.88	0.39	0.42	1.47	0.03	1.89	-55.80	-51.58		GU722
LAXGU723	34 14.74	118 22.00	922.0	979566.31	-26.93	-58.38	-54.02	0.38	0.07	1.49	0.03	1.56	-57.20	-53.00		GU723
LAXGU724	34 14.77	118 22.10	923.9	979567.35	-27.75	-59.26	-54.90	0.38	0.09	1.47	0.04	1.56	-58.09	-53.89		GU724
LAXGU725	34 15.00	118 22.11	937.6	979566.48	-27.66	-59.63	-55.20	0.39	0.08	1.51	0.03	1.59	-58.44	-54.17		GU725
LAXGU726	34 14.75	118 21.69	950.4	979567.90	-24.68	-57.10	-52.60	0.39	0.25	1.55	0.03	1.80	-55.69	-51.40		GU726
LAXGV8 1	34 12.17	118 26.87	750.9	979566.70	-41.04	-66.65	-63.10	0.32	0.0	0.71	0.0	0.71	-66.26	-62.77		GV8 1
LAXGV8 2	34 12.31	118 26.89	755.8	979565.69	-41.79	-67.56	-63.99	0.32	0.02	0.71	0.0	0.73	-67.15	-63.63		GV8 2
LAXGV8 3	34 12.43	118 26.86	761.1	979564.65	-42.50	-68.45	-64.86	0.32	0.0	0.72	0.0	0.72	-68.06	-64.51		GV8 3
LAXGV8 4	34 12.67	118 26.87	765.1	979563.20	-43.90	-70.00	-66.38	0.32	0.05	0.73	0.0	0.78	-69.54	-65.99		GV8 4
LAXGV8 5	34 12.84	118 26.87	778.3	979561.37	-44.73	-71.28	-67.60	0.33	0.02	0.73	0.00	0.75	-70.85	-67.23		GV8 5
LAXGV8 6	34 12.93	118 26.89	782.3	979560.68	-45.17	-71.85	-68.15	0.33	0.0	0.74	0.00	0.74	-71.44	-67.80		GV8 6
LAXGV8 7	34 12.99	118 26.87	787.4	979559.88	-45.57	-72.43	-68.71	0.33	0.0	0.74	0.00	0.74	-72.02	-68.36		GV8 7
LAXGV8 8	34 13.06	118 26.87	791.2	979559.22	-45.97	-72.96	-69.22	0.33	0.0	0.74	0.00	0.74	-72.55	-68.87		GV8 8
LAXGV8 9	34 13.16	118 26.87	796.8	979558.34	-46.50	-73.67	-69.91	0.33	0.0	0.75	0.00	0.75	-73.26	-69.55		GV8 9
LAXGV810	34 13.48	118 26.87	812.1	979555.98	-47.84	-75.53	-71.70	0.34	0.0	0.77	0.0	0.77	-75.11	-71.33		GV810
LAXGV811	34 13.74	118 26.95	824.9	979553.98	-48.99	-77.13	-73.23	0.35	0.0	0.77	0.0	0.77	-76.70	-72.86		GV811
LAXGV812	34 13.97	118 26.95	840.2	979551.97	-49.89	-78.54	-74.57	0.35	0.04	0.79	0.00	0.83	-78.07	-74.16		GV812
LAXGV813	34 14.13	118 26.95	850.7	979550.67	-50.42	-79.44	-75.42	0.36	0.0	0.79	0.00	0.79	-79.00	-75.04		GV813
LAXGV814	34 14.23	118 26.95	856.4	979549.80	-50.90	-80.10	-76.06	0.36	0.0	0.80	0.00	0.80	-79.66	-75.67		GV814
LAXGV815	34 14.34	118 26.97	861.4	979549.14	-51.24	-80.62	-76.55	0.36	0.0	0.81	0.00	0.81	-80.17	-76.16		GV815
LAXGV816	34 14.42	118 26.97	865.4	979548.55	-51.56	-81.08	-76.99	0.36	0.0	0.81	0.00	0.81	-80.63	-76.60		GV816
LAXGV817	34 14.46	118 26.97	870.2	979547.86	-51.86	-81.54	-77.43	0.36	0.0	0.82	0.00	0.82	-81.08	-77.03		GV817
LAXGV818	34 14.54	118 26.97	873.4	979547.46	-52.07	-81.86	-77.73	0.36	0.0	0.82	0.0	0.82	-81.40	-77.33		GV818
LAXGV819	34 14.62	118 26.97	877.4	979546.92	-52.35	-82.27	-78.12	0.37	0.0	0.83	0.0	0.83	-81.81	-77.72		GV819
LAXGV820	34 14.97	118 26.75	896.6	979544.88	-52.93	-83.51	-79.27	0.37	0.01	0.86	0.00	0.87	-83.01	-78.84		GV820
LAXGV821	34 15.06	118 26.57	909.9	979543.84	-52.90	-83.93	-79.63	0.38	0.0	0.90	0.01	0.90	-83.42	-79.19		GV821

LAXGV822	34	15.17	118	26.34	923.6	979542.53	-52.76	-84.26	-79.89	0.38	0.02	0.93	0.00	0.95	-83.69	-79.40	GV822
LAXGV823	34	15.26	118	26.24	931.2	979542.42	-52.68	-84.44	-80.04	0.39	0.0	0.95	0.00	0.95	-83.88	-79.55	GV823
LAXGV824	34	15.29	118	26.19	935.2	979542.25	-52.52	-84.41	-79.99	0.39	0.0	0.96	0.00	0.96	-83.84	-79.50	GV824
LAXGV825	34	15.33	118	26.14	939.4	979542.02	-52.41	-84.45	-80.01	0.39	0.0	0.97	0.00	0.97	-83.87	-79.51	GV825
LAXGV826	34	15.45	118	25.98	953.6	979541.30	-52.00	-84.52	-80.02	0.40	0.0	0.99	0.00	0.99	-83.93	-79.50	GV826
LAXGV827	34	15.55	118	25.84	965.8	979540.75	-51.50	-84.44	-79.88	0.40	0.0	1.01	0.00	1.01	-83.83	-79.35	GV827
LAXGV828	34	15.58	118	25.79	969.4	979540.65	-51.30	-84.37	-79.78	0.40	0.0	1.02	0.00	1.02	-83.75	-79.25	GV828
LAXGV829	34	15.62	118	25.74	973.3	979540.59	-51.05	-84.25	-79.65	0.40	0.0	1.03	0.00	1.03	-83.62	-79.11	GV829
LAXGV830	34	15.68	118	25.64	982.6	979540.39	-50.46	-83.98	-79.33	0.41	0.0	1.05	0.0	1.05	-83.34	-78.78	GV830
LAXGV831	34	15.88	118	25.44	1002.7	979540.26	-48.96	-83.19	-78.44	0.41	0.0	1.09	0.01	1.09	-82.51	-77.86	GV831
LAXGV832	34	15.92	118	25.34	1006.5	979540.45	-48.49	-82.82	-78.06	0.42	0.0	1.11	0.01	1.11	-82.13	-77.47	GV832
LAXGV833	34	16.01	118	25.23	1016.2	979540.54	-47.61	-82.27	-77.47	0.42	0.0	1.14	0.01	1.14	-81.56	-76.85	GV833
LAXGV834	34	16.04	118	25.18	1020.1	979540.81	-47.02	-81.81	-76.99	0.42	0.02	1.15	0.01	1.17	-81.06	-76.35	GV834
LAXGV835	34	16.08	118	25.09	1026.5	979541.11	-46.17	-81.18	-76.33	0.42	0.04	1.16	0.01	1.20	-80.40	-75.66	GV835
LAXGV836	34	16.14	118	25.05	1030.7	979541.02	-45.95	-81.11	-76.23	0.43	0.04	1.18	0.02	1.22	-80.31	-75.55	GV836
LAXGV837	34	16.17	118	25.00	1035.1	979541.10	-45.50	-80.80	-75.91	0.43	0.04	1.19	0.02	1.23	-80.00	-75.22	GV837
LAXGV838	34	16.23	118	24.90	1040.4	979541.28	-44.90	-80.39	-75.47	0.43	0.0	1.22	0.03	1.22	-79.60	-74.79	GV838
LAXGV839	34	16.26	118	24.86	1045.8	979541.19	-44.53	-80.20	-75.25	0.43	0.0	1.22	0.02	1.22	-79.40	-74.57	GV839
LAXGV840	34	16.31	118	24.77	1049.6	979541.16	-44.27	-80.07	-75.11	0.43	0.0	1.25	0.02	1.25	-79.25	-74.40	GV840
LAXGV841	34	16.37	118	24.68	1058.2	979540.81	-43.90	-79.99	-74.99	0.44	0.0	1.27	0.02	1.27	-79.15	-74.27	GV841
LAXGV842	34	16.43	118	24.63	1063.4	979540.55	-43.75	-80.02	-74.99	0.44	0.0	1.29	0.02	1.29	-79.16	-74.26	GV842
LAXGV843	34	16.48	118	24.54	1069.0	979540.23	-43.62	-80.07	-75.02	0.44	0.0	1.32	0.02	1.32	-79.20	-74.27	GV843
LAXGV844	34	16.56	118	24.44	1075.5	979539.76	-43.58	-80.27	-75.18	0.44	0.03	1.35	0.02	1.38	-79.33	-74.37	GV844
LAXGV845	34	16.59	118	24.39	1079.8	979539.49	-43.49	-80.32	-75.22	0.44	0.04	1.37	0.03	1.41	-79.36	-74.39	GV845
LAXGV846	34	16.67	118	24.31	1092.8	979538.44	-43.43	-80.70	-75.54	0.45	0.12	1.39	0.03	1.51	-79.64	-74.62	GV846
LAXGV847	34	16.71	118	24.25	1103.8	979537.92	-42.97	-80.62	-75.40	0.45	0.14	1.41	0.03	1.55	-79.53	-74.46	GV847
LAXGV848	34	16.77	118	24.14	1125.0	979536.74	-42.24	-80.61	-75.30	0.46	0.23	1.43	0.05	1.66	-79.41	-74.26	GV848
LAXGV849	34	16.84	118	24.07	1147.7	979535.49	-41.45	-80.60	-75.17	0.47	0.18	1.45	0.05	1.63	-79.44	-74.18	GV849
LAXGV850	34	16.94	118	23.94	1182.6	979533.62	-40.18	-80.52	-74.93	0.48	0.0	1.48	0.04	1.48	-79.52	-74.07	GV850
LAXGV851	34	16.99	118	23.86	1206.1	979532.06	-39.60	-80.74	-75.04	0.49	0.30	1.49	0.06	1.79	-79.44	-73.92	GV851
LAXGV852	34	17.06	118	23.76	1231.8	979530.37	-38.97	-80.99	-75.16	0.50	0.53	1.51	0.06	2.04	-79.44	-73.84	GV852
LAXGV853	34	17.09	118	23.62	1250.1	979529.56	-38.10	-80.74	-74.80	0.51	0.60	1.54	0.06	2.14	-79.11	-73.43	GV853
LAXGV3S1	34	8.68	118	15.10	536.9	979601.55	-21.45	-39.76	-37.22	0.23	0.0	1.36	0.01	1.36	-36.63	-36.25	GV3S1
LAXGV3S2	34	8.57	118	15.10	528.3	979603.20	-20.45	-36.47	-35.98	0.23	0.0	1.32	0.02	1.32	-37.38	-35.03	GV3S2
LAXGV3S3	34	8.52	118	15.09	523.6	979604.01	-20.02	-37.88	-35.40	0.22	0.0	1.31	0.02	1.31	-36.79	-34.46	GV3S3
LAXGV3S4	34	8.47	118	15.09	520.2	979604.59	-19.69	-37.43	-34.97	0.22	0.0	1.29	0.02	1.29	-36.36	-34.05	GV3S4
LAXGV3S5	34	8.40	118	15.09	515.0	979605.48	-19.19	-36.75	-34.32	0.22	0.0	1.28	0.02	1.28	-35.70	-33.41	GV3S5
LAXGV3S6	34	8.33	118	15.09	508.9	979606.47	-18.67	-36.03	-33.63	0.22	0.0	1.26	0.02	1.26	-34.99	-32.73	GV3S6
LAXGV3S7	34	8.24	118	15.09	500.9	979607.74	-18.03	-35.11	-32.75	0.22	0.0	1.24	0.02	1.24	-34.09	-31.87	GV3S7

CHAPTER D

MAP SHOWING CONTOURS ON THE WATER TABLE IN THE EASTERN SAN FERNANDO VALLEY, LOS ANGELES COUNTY, CALIFORNIA

By R.B. Saul and F.H. Weber, Jr.

CONTENTS

ILLUSTRATION

PURPOSE

The purpose of this map is to depict the approximate shape of the water table in the eastern San Fernando Valley in order that local changes in the slope of the table can be related to late Quaternary tectonics in conjunction with data from geologic, geophysical and elevation change studies also made for this project, as well as data and findings of past hydrologic and geologic studies. Of principal interest is the appearance of steep gradients in the water table that imply the presence of ground water barriers (possibly faults or shears) in youthful sand and gravel that constitute near-surface, water-bearing materials of the valley.

BACKGROUND

The flow of surface and ground water in the eastern San Fernando Valley is to the southeast and east, concentrated along the major drainages of Big Tujunga and Pacoima Washes and the Los Angeles River. The alluvium of the eastern San Fernando Valley is coarser than the alluvium to the west mainly because of voluminous debris fed into the valley, before flood control facilities were constructed, from the large areas of coarse crystalline rocks of the San Gabriel Mountains drained by the Big Tujunga and Pacoima drainages (California Water Rights Board, 1960, 1962; Brown, 1975). To the west, the sediments are derived locally via smaller drainages largely from shale and sandstone terranes of the Santa Monica and Santa Susana Mountains which generally yield fine-grained and less voluminous materials.

The ground water occurs not only in recent (Holocene) and older (late Pleistocene) alluvium, but also in the underlying consolidated coarse sediments of the Pacoima and Saugus Formations. Well logs generally show little lithologic distinction between late Quaternary alluvium and underlying Plio-Pleistocene Saugus Formation and Pleistocene Pacoima Formation that underlies it at the north edge and other parts of the valley. Some logs note limy material that could correlate with the carbonate-rich, uppermost beds of the Saugus Formation mapped by Saul (1975, 1979). These beds appear to constitute impermeable barriers to water in their areas of outcrop but outcrops tend to case-harden through evaporation of capillary water, so these beds may be no more effective a water barrier at depth than any of the numerous clay-rich beds in the Saugus Formation. But many of the sandy and conglomeratic beds in the Saugus Formation are permeable enough to store or transmit water as opportunity permits and may produce artesian effects at some sites. Carbonate layers in wells might also represent caliche layers in buried, older soils. For example, an old soil horizon, now partially exhumed along the base of the Santa Susana Mountains, in the vicinity of Limekiln and Aliso Canyons, contains well indurated layers of caliche (Saul, 1975, 1979). The southward and eastward extent of such deposits in the subsurface is unknown but if they are present in areas of Holocene deformation they might pond or greatly impede the movement of ground water.

Because the base of the ground water-bearing materials is uneven and has been folded and faulted through geologic time, the thickness and flow of ground water and the surface of the water table are not even. The water table in the eastern part of the valley ranges in depth from less than 50 feet to perhaps 400 feet or more (based on data from Los Angeles County Flood Control District), gradually deepening with time as water is withdrawn, but fluctuating as wet and dry rain cycles affect in-flow. Thus a picture emerges of parts of the water table representing steep, fairly rapid flow of ground water being fed to areas of deep ponding (underground "lakes" or reservoirs).

Steep gradients of the water table commonly represent ground water cascades (on the steepened base of ground water flow or on an intermediate impermeable layer) or ground water barriers created by clay-filled shears or clay gouge accompanying faults. The recognition of these features permits the inference of youthful faulting in the subsurface. Such features have been recognized previously along major faults in ground water studies of the valley by Eckis (1934), Donnan and others (1950), Wozab (1952), California Water Rights Board (1960, 1962, summarized by Brown, 1975), City of Los Angeles (1977), Los Angeles County Flood Control District (1973 and various other maps and reports) and others. The present study verifies the presence of previously recognized features and tentatively suggests several additional ones.

SOURCE, NATURE AND LIMITATIONS OF DATA

Data used in preparation of the map were obtained from files of the Los Angeles County Flood Control District. These files comprise records of wells under the jurisdiction of the Los Angeles City Department of Water and Power, other water agencies and private firms. Useful wells for the purpose of this project are those with records that show the date and depth to the water table when they were drilled. Such wells in the study area total 146; records for an additional 354 wells show the date of drilling but do not record the depth to the water table; of the few wells with unrecorded dates of drilling only a few show the depth to the water table. Of the 146 wells used, 118 were drilled during a 30-year period (1931-1960); therefore, in using these wells, the variation with time of the historic deepening of the water table is not as great a factor as if the dates were spread more evenly from 1900 to 1960 (the total span of time for which drillings of wells is recorded by the Flood Control District).

PROCEDURES

Map locations of the 146 usable wells and accompanying elevations of the water table at the time of drilling were replotted from the old 1:24,000-scale 6-minute quadrangle file sheets of the Los Angeles County Flood Control District onto the 1:24,000 scale base map made from modern quadrangle maps, used as the base map for Plates 1 and 2. Then contours of 10-foot intervals were utilized in preparation of a preliminary map in order to visualize contour patterns. Then this map was generalized by use of a 50-foot interval in order to adapt to the uneven quality of the data. These data are plentiful and even in some areas, plentiful and uneven is some areas and very sparse in other areas. By even, it is meant that wells in a particular sector were drilled close enough together in time to yield a fairly even data base for the elevation of the water table, whereas some wells clustered in another sector were drilled over a long enough time span that water table levels vary.

During the 60-year data-base period, from 1900 to 1960, the elevation of the water table in the San Fernando Valley gradually has been decreasing but the change has not been equal either spatially or chronologically. Neither are well records adequate to determine the ground water level at any one time throughout the valley in the historic past. Thus the map represents an idealized, interpretive generalization of the shape of the water table during the data-base period, but principally from 1930 to 1960.

FINDINGS

The map discloses several significant anomalies and suggests several others.

A steep gradient in the water table extends southerly across the generally eastward projection of the Mission Hills fault in the San Fernando area from just south of the intersection of San Fernando Road and Brand Boulevards to a little north of the intersection of Pacoima Wash and Laurel Canyon Boulevard, a distance of about three-fourths of a mile (1.2 km). At the more northerly point the water table is about 60 (±) feet below the ground surface and at the southerly point it lies at a depth of about 300 feet. Because of the lack of data to the east it is not certain whether this steepening trends eastward to a point north of the Pacoima Hills or whether it swings southeast toward the Verdugo fault (as shown by Wozab (1952) and Los Angeles County Flood Control (1973) on maps showing ground water contours).

A second steepening of the gradient lies about one and one-quarter miles (2 km) south of the above locality, in the vicinity of the intersection of Laurel Canyon Boulevard and Terra Bella Avenue. This steepening appears to extend eastward from the Northridge Hills fault and perhaps swings south eastward along the general trend of the Verdugo fault. Just south of this steepening lies a trough-like feature, shaped in plan somewhat like a northerly aligned hour glass, within which the water table may lie as much as 350 feet below the ground surface. This feature may reflect a series of east-trending tectonic lows and highs (plate 2d) which are bounded on the south by a possible hitherto unmapped fault whose trace extends generally eastward in the vicinity of Sherman Way (plate 2d).

South of this feature the water table lies closer to the ground surface and gradients are much less steep than to the north. Features implying the presence of faults are much more subtle than to the north. One of these features is an apparently concealed, ancient canyon that extends northwestward from the vicinity of Burroughs High School in Burbank to the vicinity of the intersection of Vineland Avenue and Victory Boulevard in North Hollywood (plate 2d). Gravity (plate 2a) also indicates the presence of such a feature which may be developed along a fault. Just south of this feature, several data points indicate an east-trending high of the water table.

At the east end of the valley, not enough data points exist to allow water-table elevation data to be used to define concealed structures; but, in conjunction with other data, the ground water data indicate that there is a small, east-trending downdropped block on the north side of the eastward projection of the Benedict Canyon, Griffith and other faults.

CHAPTER E

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